## Table C-2 – Annual unimpaired Sacramento River runoff for 1906-2009

*Data Source: http://cdec.water.ca.gov/cgi-progs/iodir/WSIHIST*

| Water Year | Sacramento River Runoff (MAF) | Water Year | Sacramento River Runoff (MAF) | Water Year | Sacramento River Runoff (MAF) | Water Year | Sacramento River Runoff (MAF) |
|---|---|---|---|---|---|---|---|
| 1906 | 26.7 | 1936 | 17.4 | 1966 | 13.0 | 1996 | 22.3 |
| 1907 | 33.7 | 1937 | 13.3 | 1967 | 24.1 | 1997 | 25.4 |
| 1908 | 14.8 | 1938 | 31.8 | 1968 | 13.6 | 1998 | 31.4 |
| 1909 | 30.7 | 1939 | 8.2 | 1969 | 27.0 | 1999 | 21.2 |
| 1910 | 20.1 | 1940 | 22.4 | 1970 | 24.1 | 2000 | 18.9 |
| 1911 | 26.4 | 1941 | 27.1 | 1971 | 22.6 | 2001 | 9.8 |
| 1912 | 11.4 | 1942 | 25.2 | 1972 | 13.4 | 2002 | 14.6 |
| 1913 | 12.9 | 1943 | 21.1 | 1973 | 20.1 | 2003 | 19.3 |
| 1914 | 27.8 | 1944 | 10.4 | 1974 | 32.5 | 2004 | 16.0 |
| 1915 | 23.9 | 1945 | 15.1 | 1975 | 19.2 | 2005 | 18.6 |
| 1916 | 24.1 | 1946 | 17.6 | 1976 | 8.2 | 2006 | 32.1 |
| 1917 | 17.3 | 1947 | 10.4 | 1977 | 5.1 | 2007 | 10.3 |
| 1918 | 11.0 | 1948 | 15.8 | 1978 | 23.9 | 2008 | 10.3 |
| 1919 | 15.7 | 1949 | 12.0 | 1979 | 12.4 | 2009 | 12.9 |
| 1920 | 9.2 | 1950 | 14.4 | 1980 | 22.3 | | |
| 1921 | 23.8 | 1951 | 23.0 | 1981 | 11.1 | | |
| 1922 | 18.0 | 1952 | 28.6 | 1982 | 33.4 | | |
| 1923 | 13.2 | 1953 | 20.1 | 1983 | 37.7 | | |
| 1924 | 5.7 | 1954 | 17.4 | 1984 | 22.4 | | |
| 1925 | 16.0 | 1955 | 11.0 | 1985 | 11.0 | | |
| 1926 | 11.8 | 1956 | 29.9 | 1986 | 25.8 | | |
| 1927 | 23.8 | 1957 | 14.9 | 1987 | 9.3 | | |
| 1928 | 16.8 | 1958 | 29.7 | 1988 | 9.2 | | |
| 1929 | 8.4 | 1959 | 12.1 | 1989 | 14.8 | | |
| 1930 | 13.5 | 1960 | 13.1 | 1990 | 9.3 | | |
| 1931 | 6.1 | 1961 | 12.0 | 1991 | 8.4 | | |
| 1932 | 13.1 | 1962 | 15.1 | 1992 | 8.9 | | |
| 1933 | 8.9 | 1963 | 23.0 | 1993 | 22.2 | | |
| 1934 | 8.6 | 1964 | 10.9 | 1994 | 7.8 | | |
| 1935 | 16.6 | 1965 | 25.6 | 1995 | 34.6 | | |

**Table C-3 – Annual unimpaired San Joaquin River runoff for 1872-1900**

*Data source: DPW (1923)*

| Water Year | Stanislaus River @ New Melones Lake | Tuolumne River @ New Don Pedro Reservoir | Merced River @ Lake McClure | San Joaquin River @ Millerton Lake | San Joaquin River Runoff |
|---|---|---|---|---|---|
| | units of acre-feet (AF) | | | | units of million acre-feet (MAF) |
| 1872 | 1,860,000 | 2,624,000 | 1,511,000 | 2,627,000 | **8.6** |
| 1873 | 959,000 | 1,543,000 | 769,000 | 1,122,000 | **4.4** |
| 1874 | 970,000 | 1,576,000 | 791,000 | 1,862,000 | **5.2** |
| 1875 | 482,000 | 982,000 | 439,000 | 887,000 | **2.8** |
| 1876 | 2,930,000 | 4,059,000 | 2,384,000 | 2,862,000 | **12.2** |
| 1877 | 408,900 | 561,000 | 220,000 | 809,000 | **2.0** |
| 1878 | 1,570,000 | 2,286,000 | 1,274,000 | 2,218,000 | **7.3** |
| 1879 | 823,000 | 1,353,000 | 659,000 | 470,000 | **3.3** |
| 1880 | 1,390,000 | 2,071,000 | 1,132,000 | 3,349,000 | **7.9** |
| 1881 | 970,000 | 1,576,000 | 791,000 | 2,740,000 | **6.1** |
| 1882 | 944,000 | 1,526,000 | 764,000 | 1,000,000 | **4.2** |
| 1883 | 1,020,000 | 1,600,000 | 813,000 | 1,392,000 | **4.8** |
| 1884 | 2,250,000 | 3,152,000 | 1,840,000 | 5,732,000 | **13.0** |
| 1885 | 582,000 | 1,097,000 | 505,000 | 1,218,000 | **3.4** |
| 1886 | 2,070,000 | 2,929,000 | 1,692,000 | 5,211,000 | **11.9** |
| 1887 | 619,000 | 1,139,000 | 538,000 | 1,479,000 | **3.8** |
| 1888 | 540,000 | 1,048,000 | 478,000 | 957,000 | **3.0** |
| 1889 | 718,000 | 1,262,000 | 599,000 | 1,574,000 | **4.2** |
| 1890 | 3,580,000 | 5,099,000 | 2,955,000 | 4,349,000 | **16.0** |
| 1891 | 959,000 | 1,543,000 | 769,000 | 1,227,000 | **4.5** |
| 1892 | 1,050,000 | 1,650,000 | 846,000 | 1,931,000 | **5.5** |
| 1893 | 2,150,000 | 3,036,000 | 1,758,000 | 1,914,000 | **8.9** |
| 1894 | 1,860,000 | 2,624,000 | 1,511,000 | 1,331,000 | **7.3** |
| 1895 | 2,700,000 | 3,795,000 | 2,236,000 | 2,786,700 | **11.5** |
| 1896 | 1,380,000 | 1,588,100 | 1,110,000 | 1,985,700 | **6.1** |
| 1897 | 1,920,000 | 2,437100 | 1,566,000 | 2,219,700 | **8.1** |
| 1898 | 498,000 | 960,500 | 450,000 | 922,300 | **2.8** |
| 1899 | 1,030,000 | 1,334,700 | 824,000 | 1,269,500 | **4.5** |
| 1900 | 1,350,000 | 1,628,100 | 1,099,000 | 1,343,000 | **5.4** |

## Table C-4 – Annual unimpaired San Joaquin River runoff for 1901-2009

*Data Source:* http://cdec.water.ca.gov/cgi-progs/iodir/WSIHIST

| Water Year | San Joaquin River Runoff (MAF) | Water Year | San Joaquin River Runoff (MAF) | Water Year | San Joaquin River Runoff (MAF) | Water Year | San Joaquin River Runoff (MAF) |
|---|---|---|---|---|---|---|---|
| 1901 | 9.4 | 1931 | 1.7 | 1961 | 2.1 | 1991 | 3.2 |
| 1902 | 5.1 | 1932 | 6.6 | 1962 | 5.6 | 1992 | 2.6 |
| 1903 | 5.7 | 1933 | 3.3 | 1963 | 6.2 | 1993 | 8.4 |
| 1904 | 7.6 | 1934 | 2.3 | 1964 | 3.1 | 1994 | 2.5 |
| 1905 | 5.3 | 1935 | 6.4 | 1965 | 8.1 | 1995 | 12.3 |
| 1906 | 12.4 | 1936 | 6.5 | 1966 | 4.0 | 1996 | 7.2 |
| 1907 | 11.8 | 1937 | 6.5 | 1967 | 10.0 | 1997 | 9.5 |
| 1908 | 3.3 | 1938 | 11.2 | 1968 | 2.9 | 1998 | 10.4 |
| 1909 | 9.0 | 1939 | 2.9 | 1969 | 12.3 | 1999 | 5.9 |
| 1910 | 6.6 | 1940 | 6.6 | 1970 | 5.6 | 2000 | 5.9 |
| 1911 | 11.5 | 1941 | 7.9 | 1971 | 4.9 | 2001 | 3.2 |
| 1912 | 3.2 | 1942 | 7.4 | 1972 | 3.6 | 2002 | 4.1 |
| 1913 | 3.0 | 1943 | 7.3 | 1973 | 6.5 | 2003 | 4.9 |
| 1914 | 8.7 | 1944 | 3.9 | 1974 | 7.1 | 2004 | 3.8 |
| 1915 | 6.4 | 1945 | 6.6 | 1975 | 6.2 | 2005 | 9.2 |
| 1916 | 8.4 | 1946 | 5.7 | 1976 | 2.0 | 2006 | 10.4 |
| 1917 | 6.7 | 1947 | 3.4 | 1977 | 1.1 | 2007 | 2.5 |
| 1918 | 4.6 | 1948 | 4.2 | 1978 | 9.7 | 2008 | 3.5 |
| 1919 | 4.1 | 1949 | 3.8 | 1979 | 6.0 | 2009 | 5.0 |
| 1920 | 4.1 | 1950 | 4.7 | 1980 | 9.5 | | |
| 1921 | 5.9 | 1951 | 7.3 | 1981 | 3.2 | | |
| 1922 | 7.7 | 1952 | 9.3 | 1982 | 11.4 | | |
| 1923 | 5.5 | 1953 | 4.4 | 1983 | 15.0 | | |
| 1924 | 1.5 | 1954 | 4.3 | 1984 | 7.1 | | |
| 1925 | 5.5 | 1955 | 3.5 | 1985 | 3.6 | | |
| 1926 | 3.5 | 1956 | 9.7 | 1986 | 9.5 | | |
| 1927 | 6.5 | 1957 | 4.3 | 1987 | 2.1 | | |
| 1928 | 4.4 | 1958 | 8.4 | 1988 | 2.5 | | |
| 1929 | 2.8 | 1959 | 3.0 | 1989 | 3.6 | | |
| 1930 | 3.3 | 1960 | 3.0 | 1990 | 2.5 | | |

# Appendix D. Instrumental Observations of Salinity

In Section 3, historical variations in the net quantity of water flowing from the Delta to the Suisun Bay (called net Delta outflow or NDO) and salinity in the western Delta were discussed using available observations and a suite of commonly used modeling tools. This section presents additional information on the historical variations of NDO and salinity in the western Delta and Suisun Bay discussed in Section 3.

## D.1. Introduction

### D.1.1. Salinity Units

Salinity is specified in this report either as electrical conductivity (EC, in units of microSiemens per centimeter, or μS/cm) or as a concentration of chloride in water (in units of milligrams of chloride per liter of water, or mg/L). Conversion between EC and chloride concentration is accomplished using site-specific empirical relationships developed by Kamyar Guivetchi (DWR, 1986). Table D-1 presents a sample of typical EC concentrations and their approximate equivalent chloride concentrations.

**Table D-1 – Typical electrical conductivity (EC) and equivalent chloride concentration**

| Electrical Conductivity (μS/cm) | Chloride (mg/L) |
|---|---|
| 350 | 50 |
| 525 | 100 |
| 1,050 | 250 |
| 1,900 | 500 |
| 2,640 | 700 |
| 3,600 | 1,000 |

Qualitative terms such as "fresh" and "brackish" are often used to describe relative salinity. The quantitative thresholds of average chloride concentration that distinguish fresh water from brackish water and the averaging time period vary among studies. For instance, chloride concentrations of 1,000 mg/L, 700 mg/L, and 50 mg/L have been used by different studies (Table D-2).

### D.1.2. Temporal and Spatial Variability of Salinity

The main variability in salinity along the length of the Bay-Delta system is due to the gradient from saline Pacific Ocean water (EC of approximately 50,000 μS/cm) to fresh water of the Central Valley rivers (EC of approximately 100 μS/cm). However, the salinity in the Bay-Delta varies both in space and time. It is important to clarify which time scales and measurement locations are being used when comparing and discussing salinity trends.

**Table D-2 – Metrics used to distinguish between "fresh" and "brackish" water**

| Description | Sample timing or averaging | Salinity Value | |
|---|---|---|---|
| | | Chloride (mg/L) | EC (µS/cm) |
| **Isohalines in Delta Atlas (DWR, 1995)** | Annual maximum of the daily maximum | 1,000 mg/L | 3,700 µS/cm |
| **X2 position (Jassby *et al.*, 1995)** | Daily average (or a 14-day average) | 700 mg/L | 2,640 µS/cm |
| **Barge travel by C&H[4]** | Monthly average of the daily maximum | 50 mg/L | 350 µS/cm |

Salinity in the western Delta is strongly influenced by tides. The hourly or daily variability of salinity can be much larger than the seasonal or annual variability. For instance, during the fall of 1999 (following a relatively wet year[5]), hourly EC in the San Joaquin River at Antioch varied by about 6,000 µS/cm (from about 3,000 µS/cm to 9,000 µS/cm) while the daily-averaged EC for all of 1999 ranged from about 100 µS/cm to 6,000 µS/cm (Figure D-1).

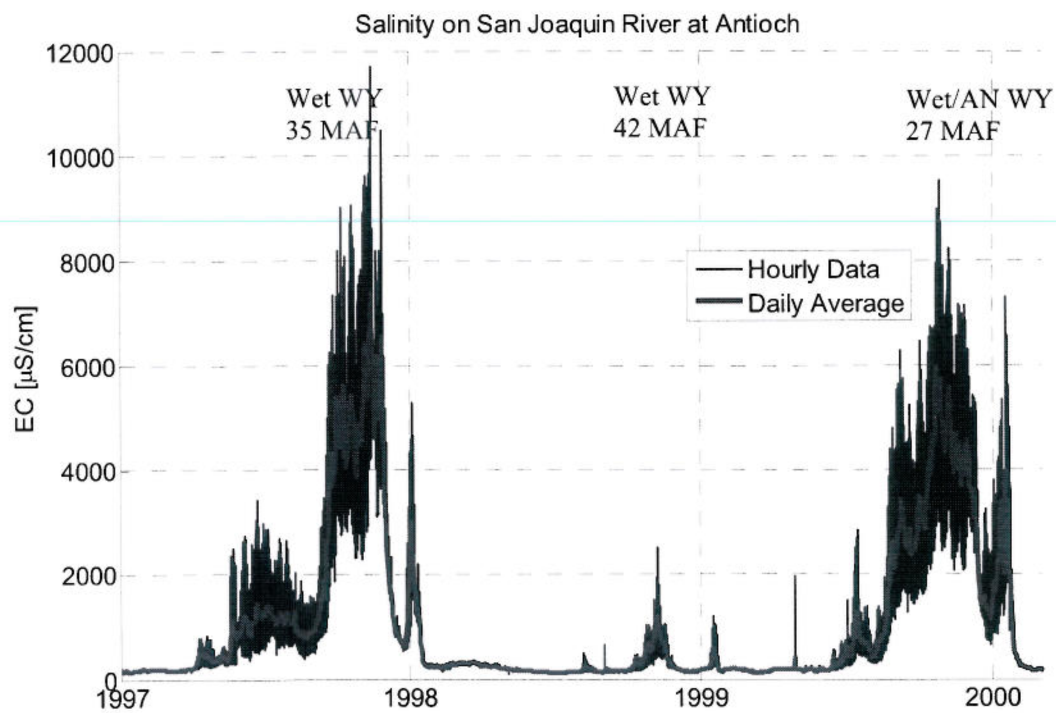



**Figure D-1 – Hourly and daily salinity variability in the San Joaquin River at Antioch**

*Total annual unimpaired Sacramento River flow and water year type is indicated for each water year.*
*Data Source: IEP Data Vaults ( http://www.iep.ca.gov/dss/ )*

[4] The California & Hawaiian Sugar Refining Corporation in Crockett (C&H) obtained its freshwater supply from barges traveling up the Sacramento and San Joaquin Rivers, generally twice a day beginning in 1908 (DPW, 1931).
[5] Water year 1999 was classified as wet using the Sacramento Valley 40-30-30 index and above-normal using the San Joaquin Valley 60-20-20 index; indices are defined in D-1641.

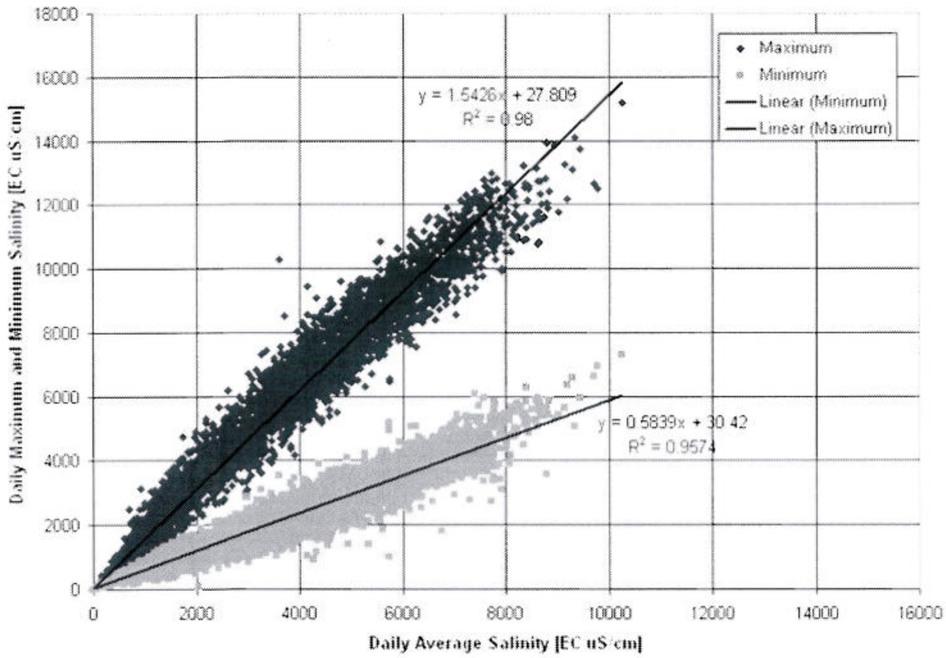



**Figure D-2 – Tidal Variability in Salinity at Antioch (1967 to 1992)**
*Data Source: IEP Data Vaults ( http://www.iep.ca.gov/dss/ )*

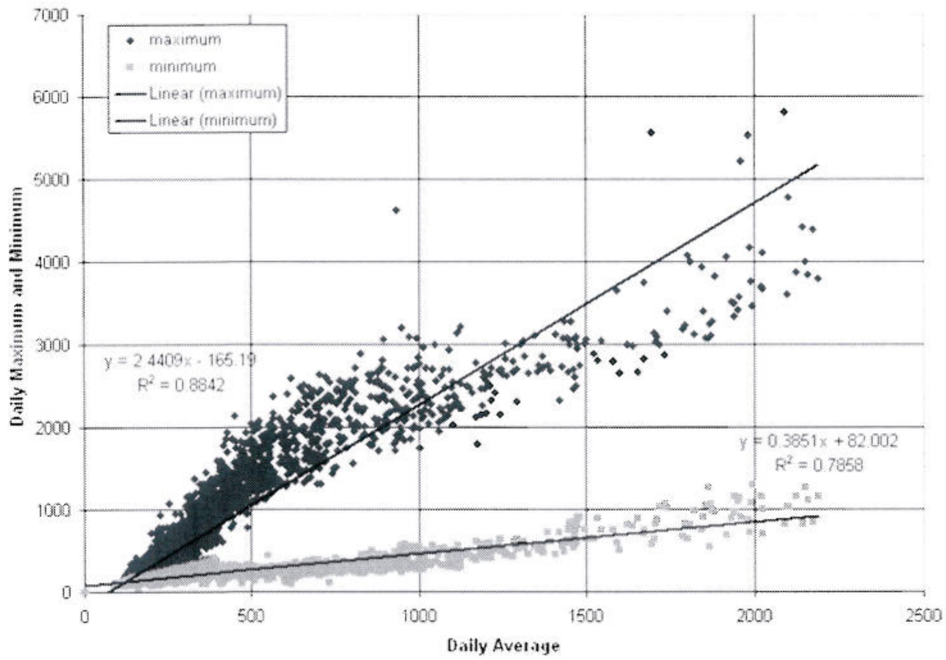



**Figure D-3 – Tidal Variability in Salinity at Rio Vista (1967 to 1992)**
*Data Source: IEP Data Vaults ( http://www.iep.ca.gov/dss/ )*

The high tide maximum, low tide minimum, and daily-averaged salinity at a given location are very different. As shown in Figure D-2, the daily maximum salinity in the San Joaquin River at Antioch can be double the daily-averaged salinity. Because of the large tidal variability in salinity, any comparisons of salinity observations should be at the same phase of the tide, or at least take into account tidal variability.

Similarly, as shown in Figure D-3, the daily maximum salinity in the Sacramento River at Rio Vista can be 170-400% of the daily average salinity. The daily minimum at Rio Vista may be 10-65% of the daily average.

## *D.2. Variations in the Spatial Salinity Distribution*

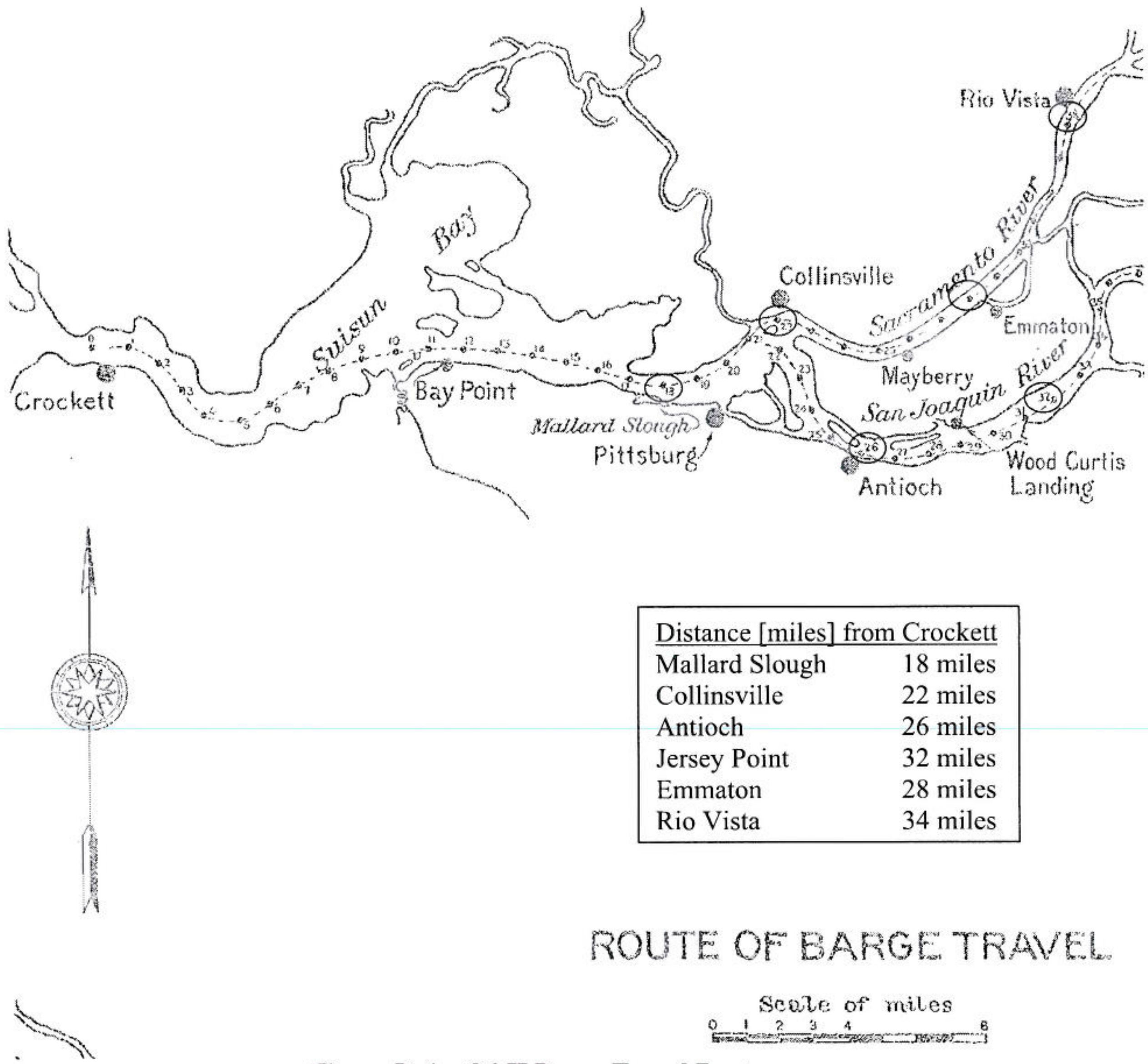
Observations examined in this section and Section 3.3 include records from the early 1900's from the California & Hawaiian Sugar Refining Corporation in Crockett (C&H) and the long-term monitoring data from the Interagency Ecological Program (IEP). Estimates of salinity at specific locations of interest were obtained from DWR's DSM2 model and Contra Costa Water District's salinity-outflow model (also known as the G-model) (Denton, 1993). Estimates of salinity intrusion were obtained using the K-M equation (Kimmerer and Monismith, 1992).

### D.2.1. Distance to Freshwater from Crockett

The California & Hawaiian Sugar Refining Corporation in Crockett (C&H) obtained its freshwater supply from barges traveling up the Sacramento and San Joaquin Rivers, generally twice a day beginning in 1905 through 1929 or later (DPW, 1931). The salinity information recorded by C&H is the most detailed salinity record available prior to the intensive salinity monitoring by the State of California, which started in 1920. This section presents a comparison of the salinity observations of C&H with recent monitoring data and modeling results to determine how the managed salinity regime of the late 20$^{th}$ Century compares to the salinity regime of the early 1900's.

#### Data Sources and Methods

**C&H data:** C&H operations required water with less than 50 mg/L chloride concentration. According to DPW (1931), the C&H barges typically traveled up the river on flood tide and returned downstream on ebb tide. Since the maximum daily salinity for a given location in the river channel typically occurs about one to two hours after high slack tide, the distance traveled by the C&H barges represents approximately the daily maximum distance to 50 mg/L water from Crockett. The monthly minimum, average, and maximum distance traveled by C&H barges are shown in Figure D-4 and Figure D-5. For the following analysis, monthly averages of the C&H daily maximum distances were extracted from Figure D-5 for the period of 1908-1918 (after 1917, extensive salinity intrusion was reported and agricultural diversions reportedly started affecting flows into the Delta).




| Distance [miles] from Crockett | |
|---|---|
| Mallard Slough | 18 miles |
| Collinsville | 22 miles |
| Antioch | 26 miles |
| Jersey Point | 32 miles |
| Emmaton | 28 miles |
| Rio Vista | 34 miles |

**Figure D-4 – C&H Barge Travel Routes**

*Map adapted from DPW (1931). Red circles indicate locations of landmarks, with distance from Crockett listed in the inset box.*

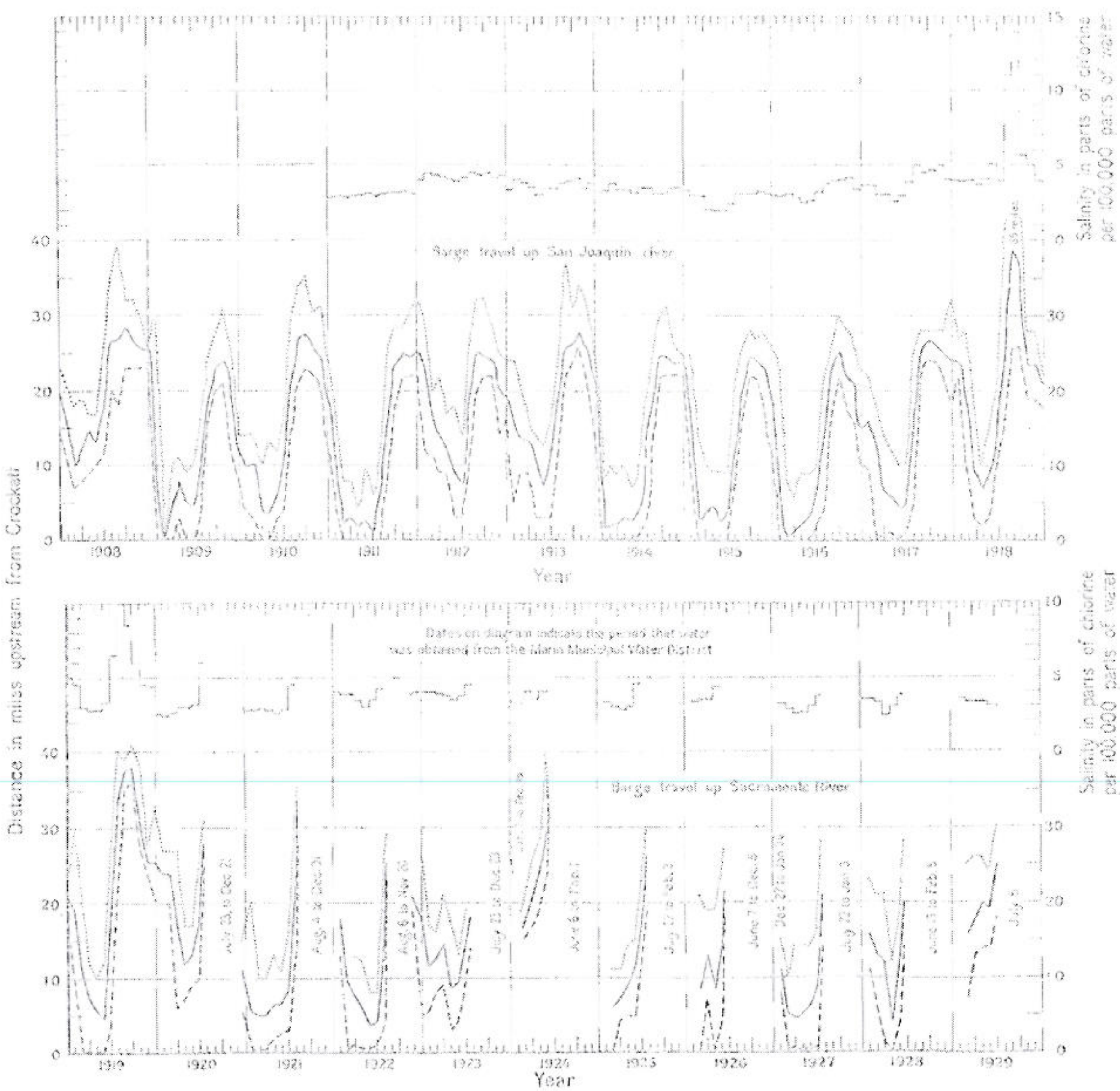



**Figure D-5 – C&H Barge Travel and Quality of Water obtained**

*C&H barge travel up the San Joaquin River (1908 through 1918, top panel) and Sacramento River (1919 through 1929, bottom panel). The lower three lines on each panel (reference to the left axes) indicate the monthly minimum (dashed line), monthly maximum (dotted line), and monthly average (solid line) distance traveled by C&H barges to obtain their fresh water supply. The uppermost solid line on each panel (reference to the right axes) indicates the average monthly salinity of the water obtained by the barges. Figure adapted from DPW (1931)*

From 1908 through 1917, C&H was able to obtain water with less than 50 mg/L chlorides within 30 miles of Crockett on average (below Jersey Point on the San Joaquin River). In 1918, the salinity of the water obtained by C&H barges had increased due to a combination of a lack of precipitation and upstream diversions (especially for newly introduced rice cultivation) (DPW, 1931). During August and September 1918, salinity exceeded 60 mg/L chloride, and the C&H barges traveled farther upstream than any time previously recorded.

In 1919, a wetter year than 1918, salinity was high for an even longer period of time, most likely due to increased upstream diversions for irrigation. Salinity exceeded 60 mg/L chloride during July, August, and September. Beginning in 1920, C&H abandoned the Sacramento and San Joaquin Rivers during the summer and fall seasons, replacing the water supply with a contract from Marin County. However, even during the driest years of the 1920's, C&H obtained water with less than 50 mg/L chloride below the confluence of the Sacramento and San Joaquin Rivers during a portion of every year.

**Salinity observations from the Interagency Ecological Program (IEP):** Long-term monitoring of electrical conductivity (EC) at multiple stations within the Bay and Delta began around 1964. Publicly-available daily-averaged data were obtained for this analysis from the Interagency Ecological Program (IEP) data vaults (Table D-3).

**Table D-3 – Overview of long-term salinity observation records from IEP**
*(see http://www.iep.ca.gov/dss/)*

| *Location* | *Station* | *Source* | *Data* |
|---|---|---|---|
| Selby | RSAC045 | USGS-BAY | Historical |
| Martinez | RSAC054 | CDEC | Real-time |
| Benicia Bridge | RSAC056 | USBR-CVO | Historical |
| Port Chicago | RSAC064 | USBR-CVO | Historical |
| Mallard | RSAC075 | CDEC | Real-time |
| Pittsburg | RSAC077 | USBR-CVO | Historical |
| Collinsville | RSAC081 | USBR-CVO | Historical |
| Emmaton | RSAC092 | USBR-CVO | Historical |
| Rio Vista | RSAC101 | USBR-CVO | Historical |
| Georgiana Slough | RSAC123 | DWR-ESO-D1485C<br>DWR-CD-SURFWATER | Historical<br>Historical |
| Greens Landing | RSAC139 | USBR-CVO | Historical |
| Antioch | RSAN008 | USBR-CVO | Historical |
| Jersey Pont | RSAN018 | USBR-CVO | Historical |
| Bradford Point | RSAN024 | USBR-CVO | Historical |
| San Andreas Landing | RSAN032 | USBR-CVO | Historical |

**Delta Simulation Model (DSM2) Historical Simulation:** The DSM2 historical simulation (1989-2006) was used to provide estimates of water quality to complement the limited field data from IEP. Because DSM2 has a very detailed spatial computational network covering the Delta and Suisun Bay, DSM2 can output much more detailed spatial and temporal salinity information than just the water quality at the IEP monitoring stations. DSM2 results include the daily-averaged EC at each model node along the lower Sacramento and San Joaquin Rivers. The location of the 350 μS/cm EC isohaline (corresponding to 50 mg/L chloride) was identified from the DSM2 results and compared with the equivalent C&H and IEP data.

**Analysis time frame:** The first decade of C&H barge travel (1908-1917) was a relatively wet period compared to the entire period of record (1906-2006) (Figure D-6). To compare conditions under similar hydrological conditions, specific recent decades (Figure D-6(a)) and select recent years (Figure D-6(b)) were selected that have comparable or slightly wetter hydrology than the C&H years. The periods 1966-1975 and 1995-2004 have similar annual unimpaired Sacramento River flow to the C&H data period (1908-1917) (see Figure D-6(a)). In addition, two wet years (1911 and 1916) and two dry years (1913 and 1918) selected from the C&H time period were compared with two wet years (1969 and 1998) and two dry years (1968 and 2002) from the IEP record.

**Limitations of the analysis**: The C&H data approximately represent the maximum daily salinity at a given location, whereas recent conditions (IEP or DSM2 data) are represented by the daily-averaged salinity. The estimates of the distance that must be traveled to reach fresh water under current conditions are, therefore, underestimated.

In addition, the C&H barges traveled up the San Joaquin River from 1908 through 1917, yet the equivalent travel distance for C&H barges under current conditions are estimated for the Sacramento River, and not the San Joaquin River. Under present-day conditions, the upstream distance to fresh water on the San Joaquin River is greater than for the Sacramento River, so this approach will also serve to underestimate the actual distance that C&H barges would have to travel under present-day conditions.

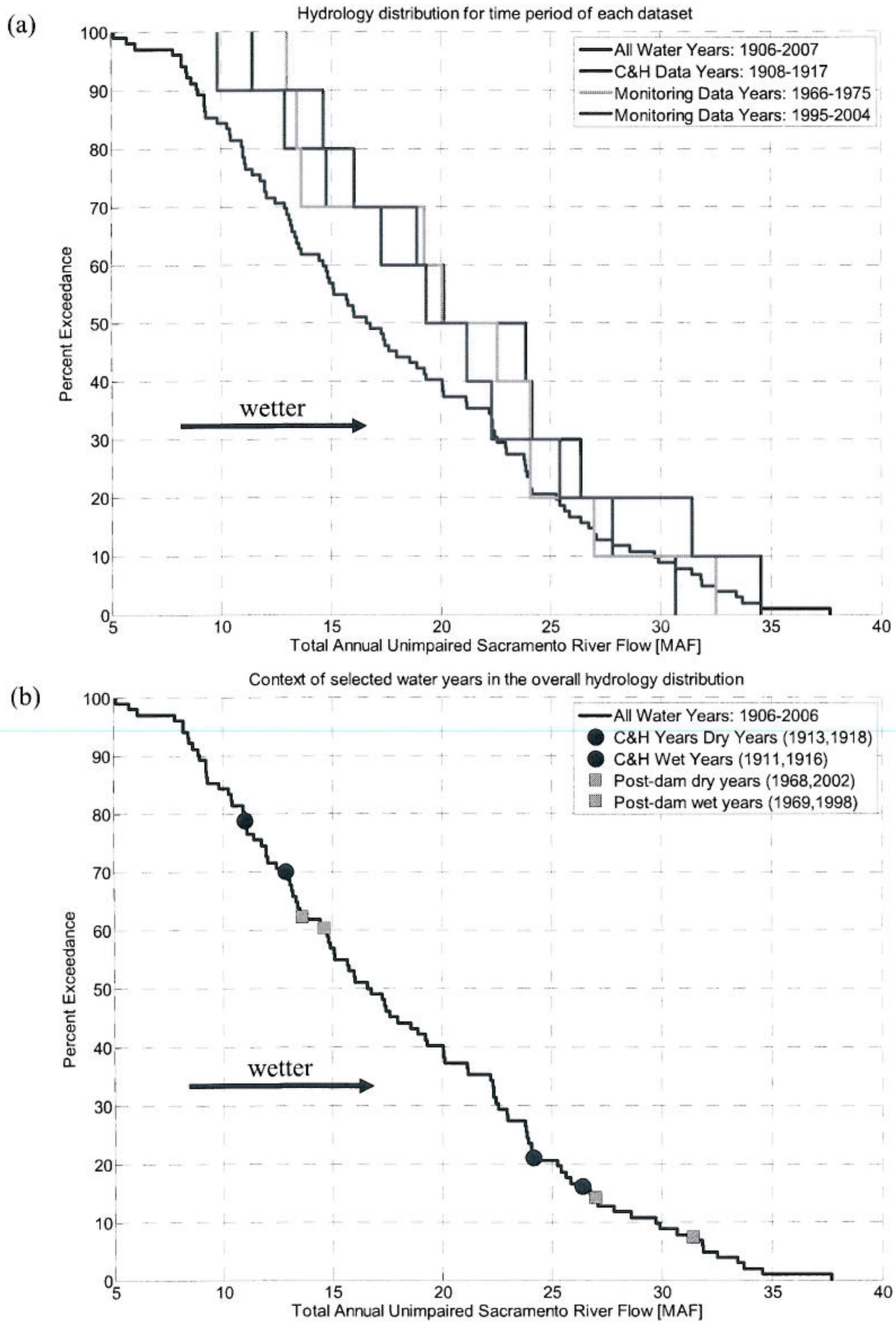



**Figure D-6 – Hydrologic Context for Analysis of Distance to Fresh Water**

*(a) Hydrology distribution for water years 1906 to 2007, and select decades.*

*(b) Hydrology distribution for water years 1906 to 2007, with select water years shown for context.*

## *Results and Discussion*

### Selected Wet Years

As shown in Figure D-7, the salinity patterns during the two selected C&H-era wet years, 1911 and 1916, are similar to each other. During these wet years, the location of 50 mg/L chloride water is west of Martinez for about 4-5 months (late February to early August in 1911 and from early February to late June in 1916). In contrast, during recent wet years 1969 and 1998, water with 50 mg/L chlorides or less was west of Martinez for only about 6 weeks in February and March. This comparison shows that in 1969 and 1998 the western Delta was saltier in the fall and spring than it was in 1911 and 1916, and salinity intrusion occurred much earlier in 1969 and 1998.

If barges were still traveling up the Sacramento River today to find fresh water, they would have to travel farther during the fall, spring, and summer than the C&H barges traveled during similar wet years. In 1916, fresh water retreated upstream about one month earlier than in 1911, possibly influenced by the increasing upstream diversions during 1911-1916 (see Figure 1-3). In recent years with even greater unimpaired runoff, fresh water retreats two to three months earlier than in 1916. Additionally, fresh water reaches Martinez for a much shorter period of time, about less than one month in recent years compared to four and five months during 1916 and 1911, respectively.

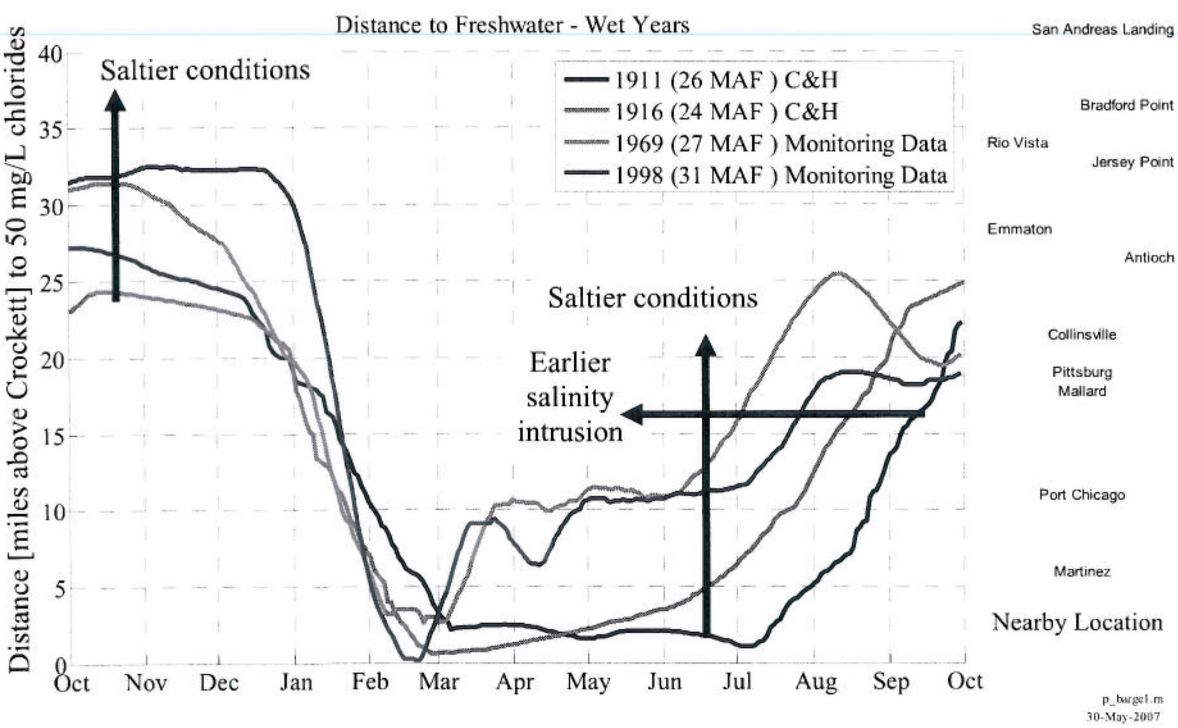
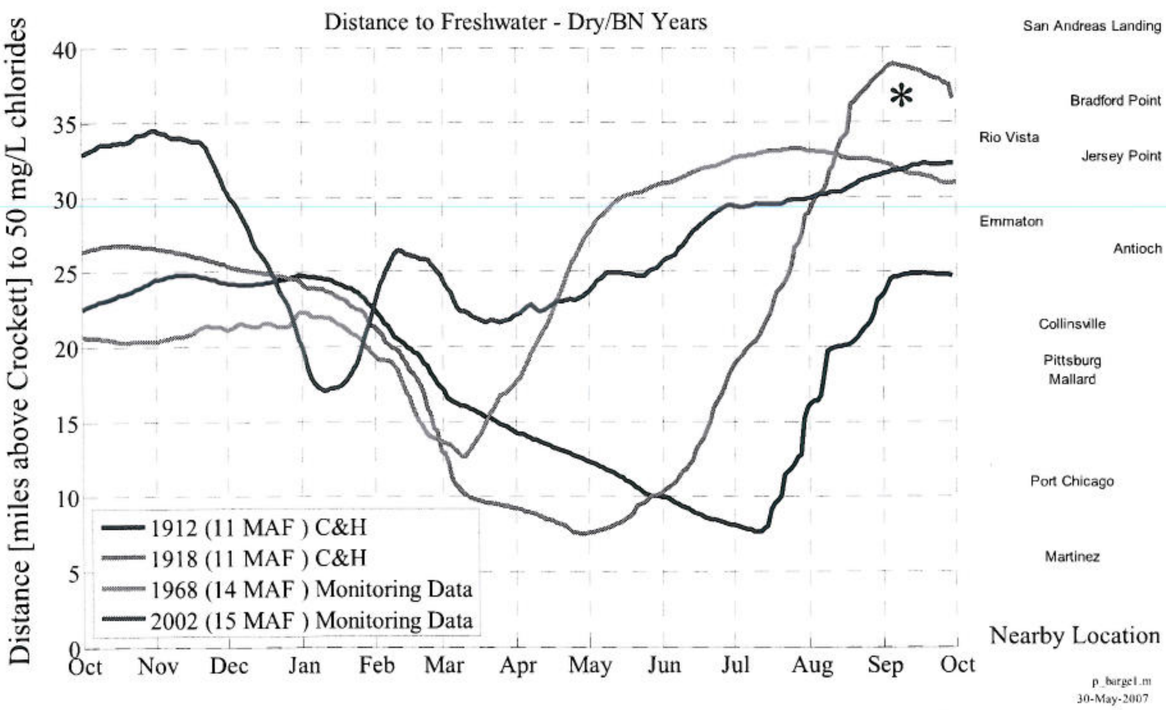



**Figure D-7 – Distance to Fresh Water in Select Wet Years**

## Selected Dry Years

Figure D-8 shows that the most visible difference between the distance to fresh water in dry years of the early 1900's and more recent dry years is the substantial increase in distance to fresh water, particularly from April through June. This indicates the spring was much fresher during the dry years of the early 1900's, before large upstream reservoirs were built to capture the spring runoff. In dry and below-normal water years under today's conditions, barges would have to travel farther during spring, summer and fall than they traveled in the early 20th Century.

The C&H barge travel distance in the dry years of 1913 and 1918 are quite different, especially the additional 10 miles of distance to fresh water traveled in August and September of 1918. C&H recorded relatively high salinity (greater than 110 mg/L chlorides) above Bradford Point on the San Joaquin in 1918, which is greater than observed salinity on the Sacramento River near Rio Vista in similar water years. This may be partially explained by the development of the rice cultivation industry around 1912 (DPW, 1931) and increased upstream diversions when seasonal river flows were already low.




* During August and September 1918, average water quality obtained by C&H exceeded 110 mg/L chlorides

**Figure D-8 – Distance to Fresh water in Select Dry or Below Normal Years**

Figure D-9 shows the exceedance probabilities for distance traveled up the Sacramento River for different salinity levels. During 1908-1917, on a monthly-averaged basis, C&H barges had to travel above the confluence of the Sacramento and San Joaquin Rivers (approximately 22 miles above Crockett) about 26% of this time period to reach water with salinity less than

350 μS/cm EC (about 50 mg/L chlorides). In contrast, from 1995-2006, DSM2 simulations suggest that barges would have to travel above the confluence approximately 56% of the time to reach water with salinity of 350 μS/cm EC.

The location of the 50 mg/L chloride isohaline during 1908-1917 approximately corresponds to the location of X2 (2,640 μS/cm EC, or 700 mg/L chlorides) during 1995-2006 (Figure D-9). This is equivalent to more than a 7-fold increase in salinity from the early 1900's to the present day.

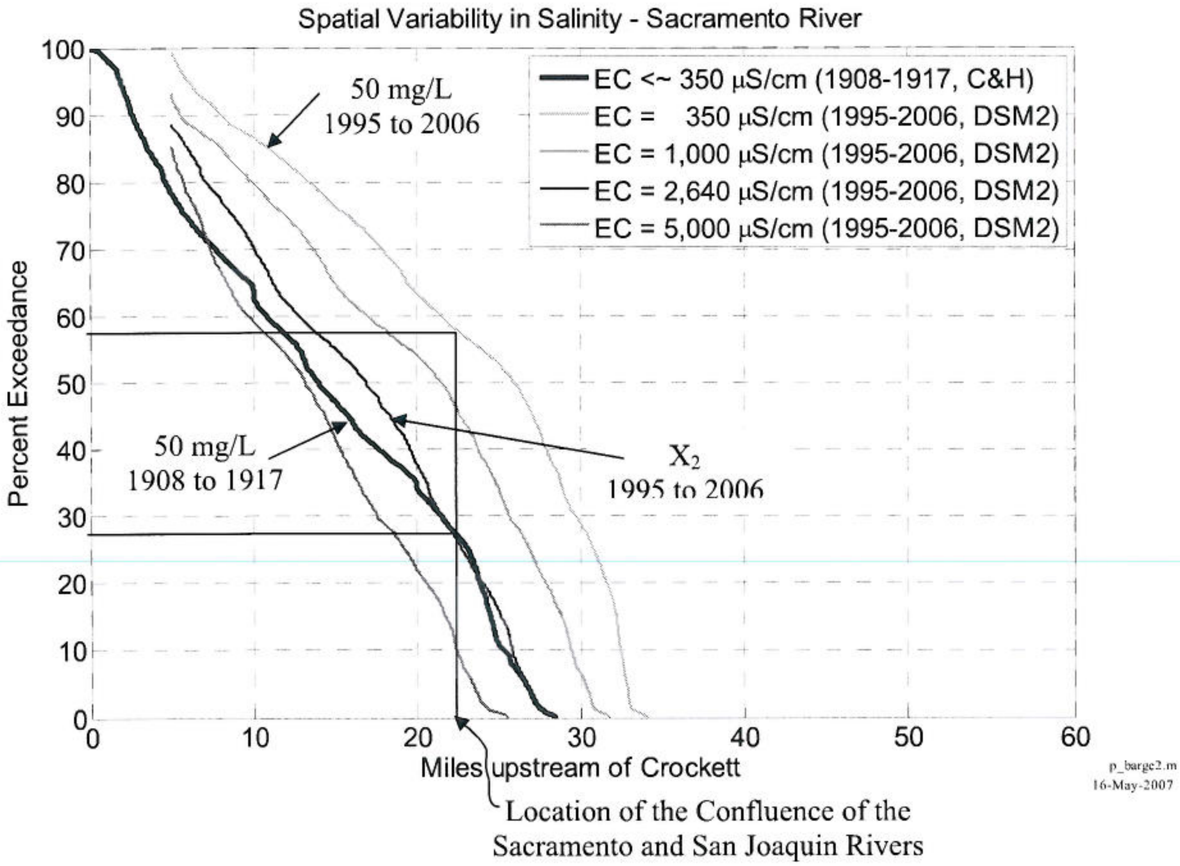



**Figure D-9 – Distance along the Sacramento River to Specific Salinity Values**

## D.2.2. Maximum Annual Salinity Intrusion Before and After Large-scale Reservoir Construction

Figure D-10 shows maximum salinity intrusion during 1921-1943 (pre-CVP period), prior to the completion of the Shasta Dam of the Central Valley Project in 1945. Salinity intrusion is presented in terms of contours of 1,000 mg/L chlorides. Figure D-11 shows the maximum salinity intrusion during the post-CVP period of 1944-1990. These figures indicate the pre-CVP period experienced greater salinity intrusion than the post-CVP period, with seawater intruding farther into the Delta during 6 of the 24 pre-CVP years (1920, 1924, 1926, 1931, 1934, and 1939) than in any of the 47 years in the post-CVP period (1944-1990).

The extreme salinity intrusion during the pre-CVP period was due, in part, to relatively low runoff during these years. Meko *et al.* (2001a) determined that the period from 1917 through 1936 was the driest 20-year period in the past 400 years; this long-term drought encompassed 16 of the 24 years in the pre-CVP period. In addition, estimates of unimpaired runoff from the Sacramento River (obtained from http://cdec.water.ca.gov/cgi-progs/iodir/WSIHIST) indicate that the Sacramento River had 6 critical water years during the 24-year period of 1920-1943, whereas, the Sacramento River had only 4 critical water years during the 47-year period of 1944-1990.

Figure D-12 shows that the peak salinity intrusion during the pre-CVP period occurred between mid-August and mid-September, while peak salinity intrusion during the first portion of the the post-CVP period (1944-1960) occurred between late-July and late-August. Salinity intrusion during the pre-CVP period was not only affected by relatively low runoff, but also by extensive upstream diversions (DPW, 1931).

The salinity investigations of the pre-CVP era found that the extreme salinity intrusion was larger than any previous intrusions known to local residents and concluded the intrusion was due, in part, to the extensive upstream diversions. As observed in DPW (1931):

> "Under conditions of natural stream flow before upstream irrigation and storage developments occurred, the extent of saline invasion and the degree of salinity reached was much smaller than during the last ten to fifteen years." (DPW, 1931, page 15)
>
> "Beginning in 1917, there has been an almost unbroken succession of subnormal years of precipitation and stream flow which, in combination with increased irrigation and storage diversions from the upper Sacramento and San Joaquin River systems, has resulted in a degree and extent of saline invasion greater than has occurred ever before as far as known." (DPW, 1931, page 15)
>
> "The abnormal degree and extent of saline invasion into the delta during recent years since 1917 have been due chiefly to: first, subnormal precipitation and run-off with a subnormal amount of stream flow naturally available to the delta, and second, increased upstream diversions

> for irrigation and storage on the Sacramento and San Joaquin River systems, reducing the inflow naturally available to the delta. It is probable that the degree of salinity in the lower channels of the delta and the extent of saline invasion above the confluence of the Sacramento and San Joaquin rivers have been about doubled by reason of the second factor." (DPW, 1931, page 42)

Conclusions from DPW (1931) and similar investigations have been corroborated by paleosalinty studies (see Section 2.3), which indicate that Browns Island in the western Delta was a freshwater marsh for approximately 2,500 years until salinity intruded in the early 20$^{th}$ Century.

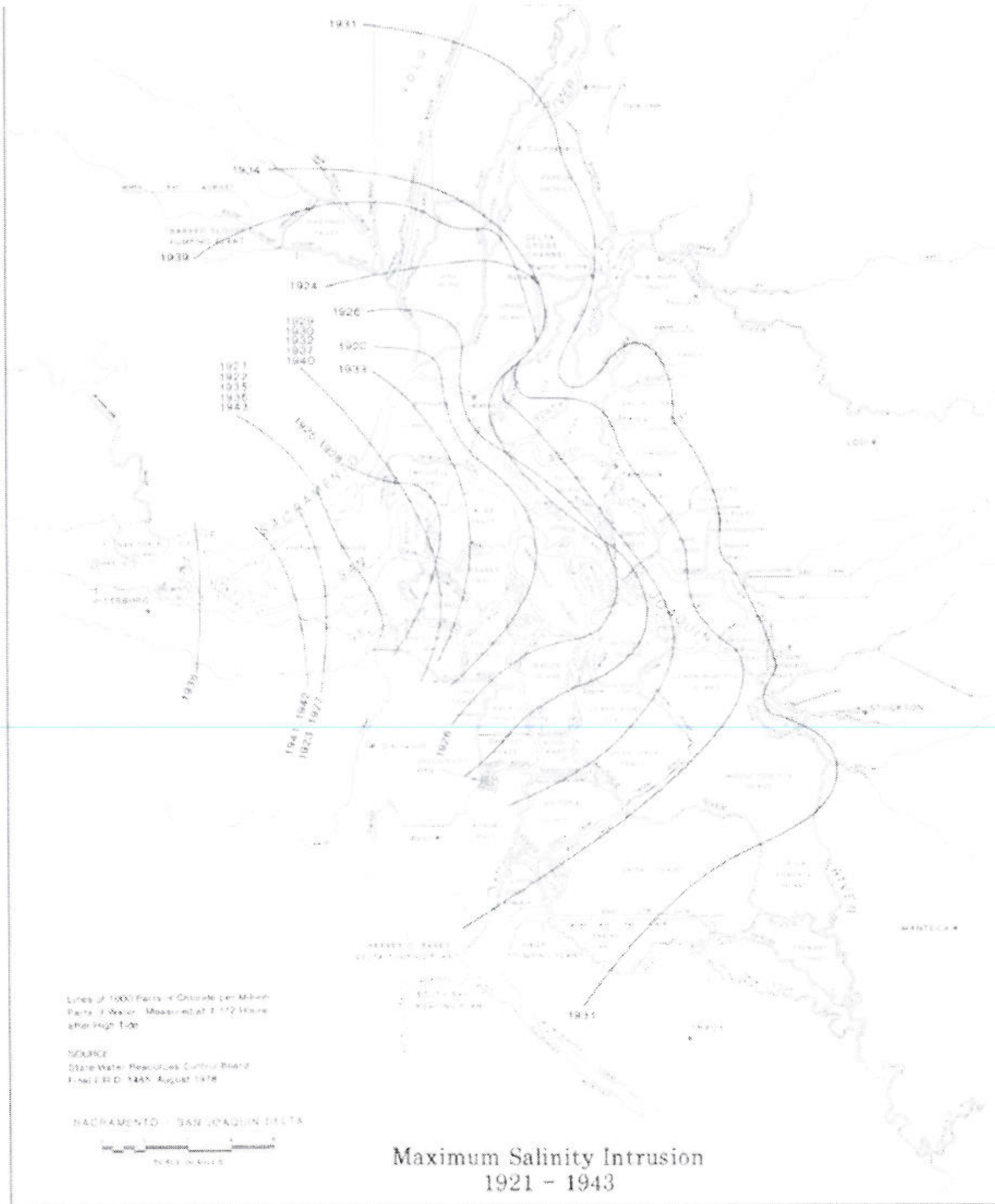



**Figure D-10 – Salinity intrusion during pre-CVP period, 1921-1943 (DWR, 1995)**

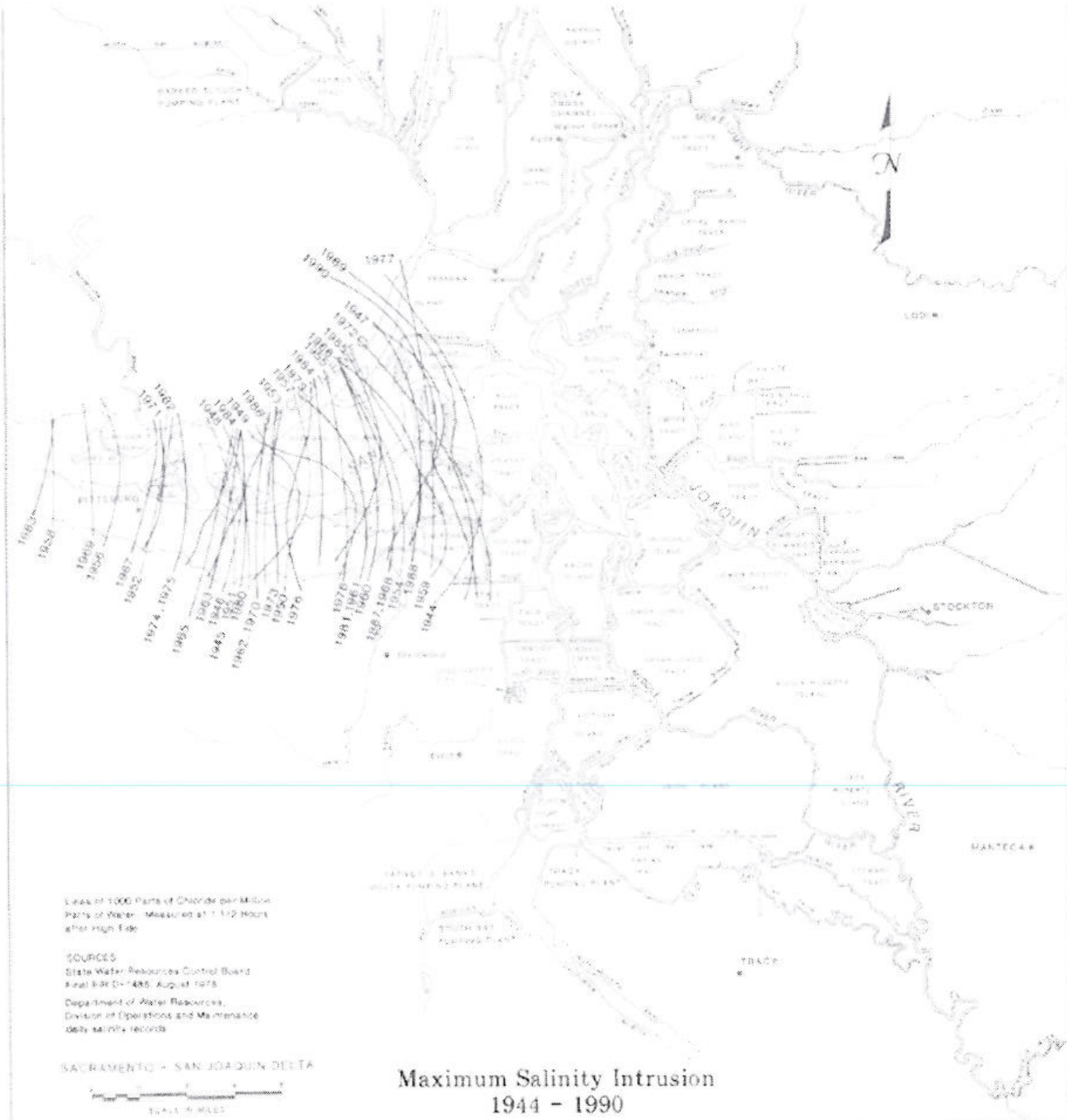



**Figure D-11 – Salinity intrusion during post-CVP period, 1944-1990 (DWR, 1995)**

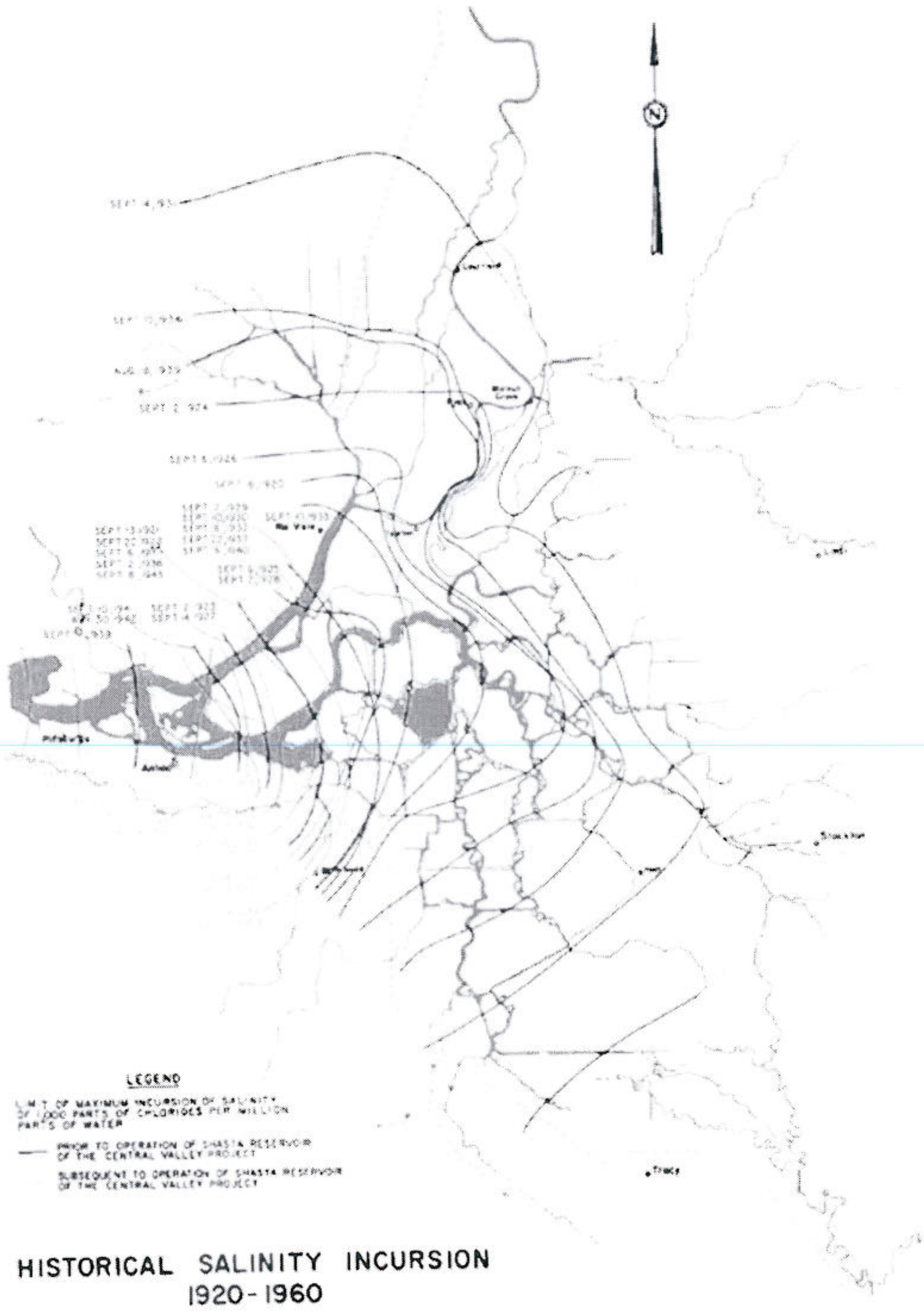



**Figure D-12 – Salinity intrusion during 1920-1960 (DWR, 1960)**

Figure D-13 illustrates the maximum annual salinity intrusion for comparable dry years[6]. Water year 1913 experienced the least extent of intrusion, most likely because upstream diversions were significantly less than in later years. Water years 1926 and 1932 were subject to extensive upstream agricultural diversions, while water years 1979 and 2002 had the benefit of the CVP and SWP to provide "salinity control". The CVP and SWP operations now regulate the amount of freshwater flowing through the Delta in order to prevent extreme salinity intrusions such as those observed during the 1920's and 1930's.

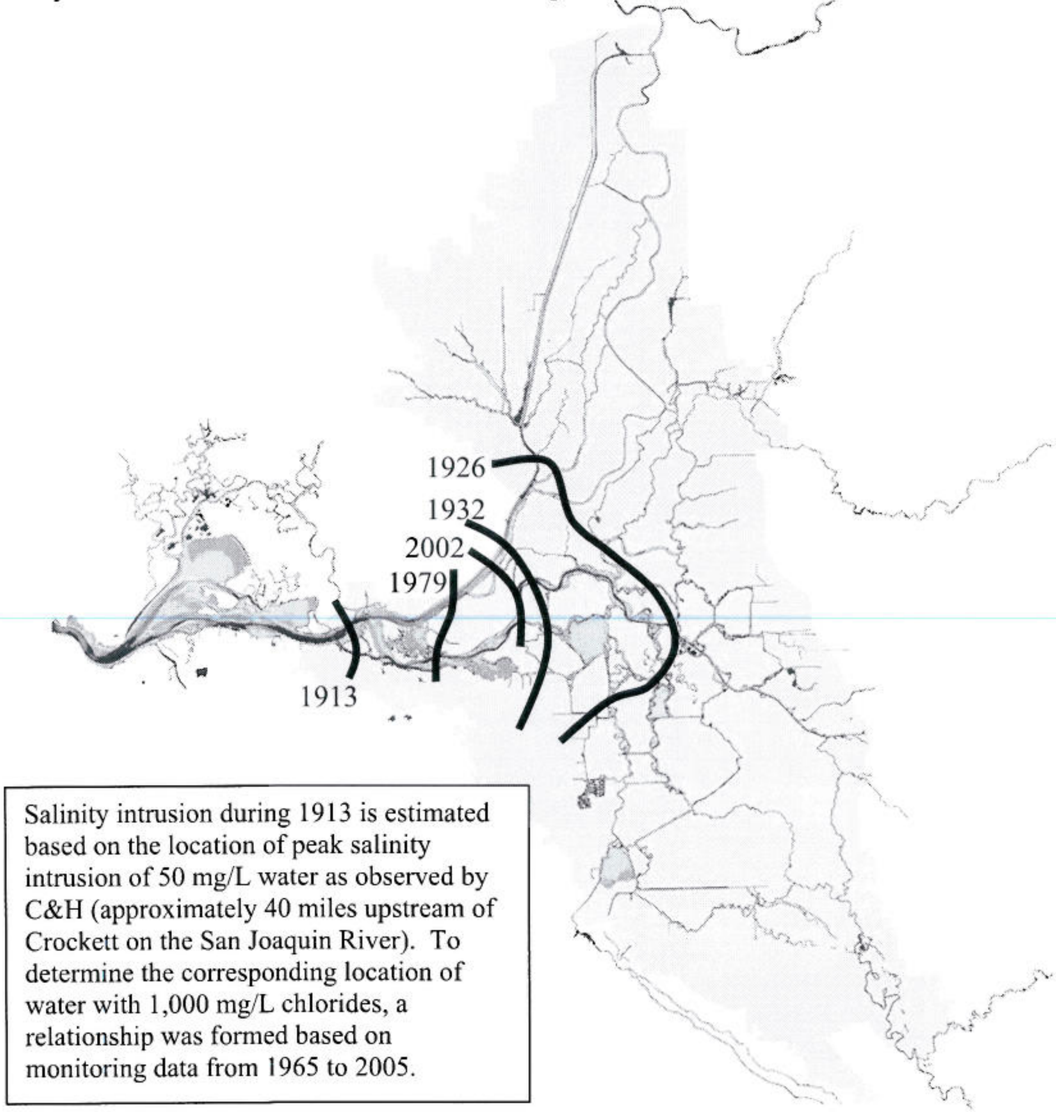



**Figure D-13 – Annual Maximum Salinity Intrusion for relatively dry years**

*Salinity intrusion for <u>relatively dry water years</u> with similar total annual unimpaired runoff, using 1,000 mg/L chloride concentration to distinguish the extent of intrusion.*

[6] Hydrological metrics from http://cdec.water.ca.gov/cgi-progs/iodir/wsihist for comparison: total unimpaired Sacramento River and San Joaquin River flow for water years 1913, 1926, 1932, 1979, and 2002 was 15.9 MAF, 15.3 MAF, 19.8 MAF, 18.4 MAF, and 18.7 MAF, respectively; Sacramento River water year type index for water years 1913, 1926, 1932, 1979, and 2002 was 6.24, 5.75, 5.48, 6.67, and 6.35, respectively; and San Joaquin River water year type index for water years 1913, 1979, and 2002 was 2.00, 2.30, 3.41, 3.67, and 2.34, respectively.

## D.3. *Temporal Variability of Salinity in the Western Delta*

### D.3.1. Seasonal Salinity at Collinsville

Collinsville, near the confluence of the Sacramento and San Joaquin Rivers, was one of the first long-term sampling locations implemented by the State of California. The Suisun Marsh Branch[7] of the DWR estimated monthly average salinity at Collinsville for the period 1920-2002, using a combination of 4-day TDS (total dissolved solids) grab samples from 1920-1971 and EC measurements from 1966-2002. Data from the overlap period of 5 years between the TDS grab samples and EC measurements were used in a statistical regression model, and the monthly averaged 4-day TDS samples were converted to monthly average EC (Enright, 2004). The result of this regression analysis was a time series of monthly EC values at Collinsville for the period of 1920-2002.

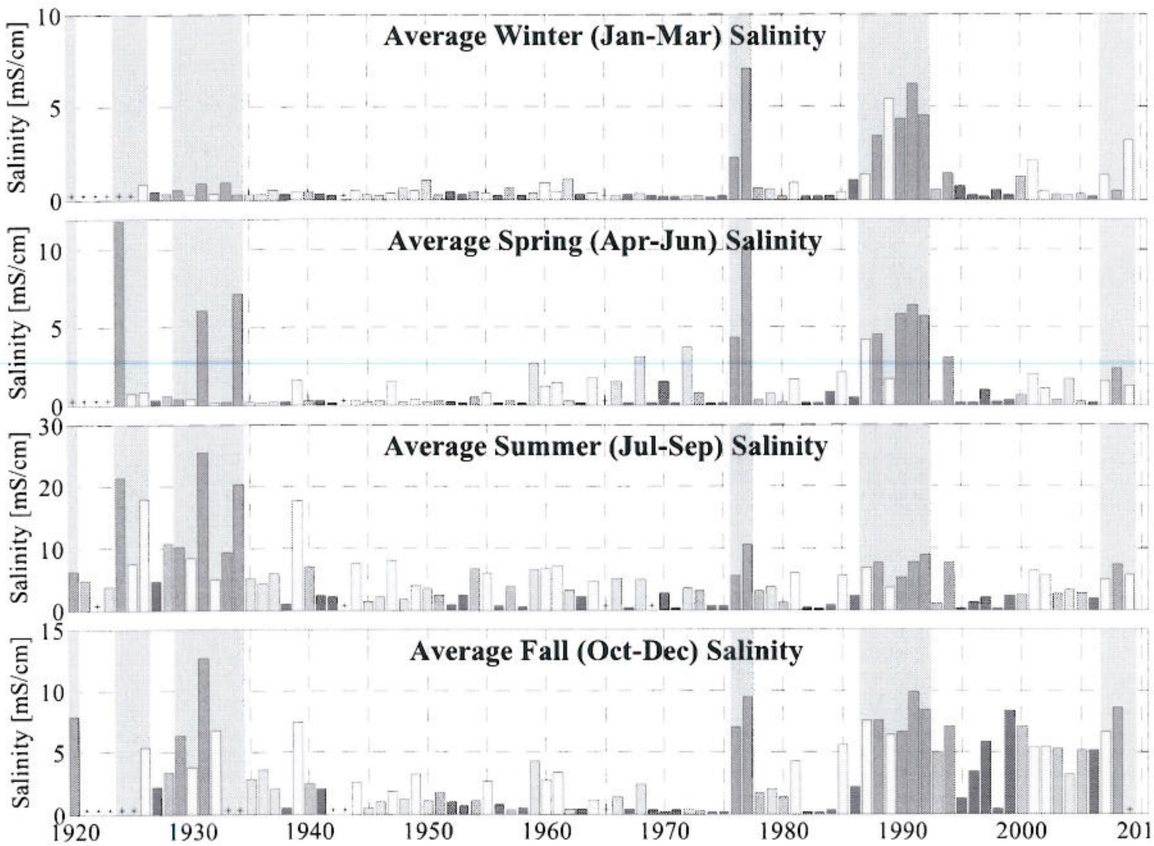



**Figure D-14 – Average Seasonal Salinity at Collinsville**

[7] Data provided by Chris Enright (DWR), personal communication, 2007.

## D.3.2. Effects of Water Management on Salinity at Collinsville

In order to compare the effects of water management on salinity at Collinsville, an empirical model of salinity transport (Denton (1993), Denton and Sullivan (1993)) was used in the following analyses. Contra Costa Water District's salinity-outflow model (also known as the G-model) estimates salinity in the western Delta as a function of NDO. Estimates of salinity at Collinsville were derived for both actual historical flow (1930-2008) and unimpaired flow (1922-2003) conditions.

Figure D-15 shows the estimated monthly-averaged salinity at Collinsville under unimpaired and actual historical flow conditions. The predicted seasonal and annual variations of EC at Collinsville are dependent on corresponding variations of NDO under both unimpaired and actual flow conditions. Water management practices have a significant effect on the seasonal variability of salinity at Collinsville, particularly during dry years (1930's, 1976-1977 and 1987-1993), when Collinsville experiences a much greater range of monthly-averaged salinity under actual historical conditions than would be the case under unimpaired conditions.

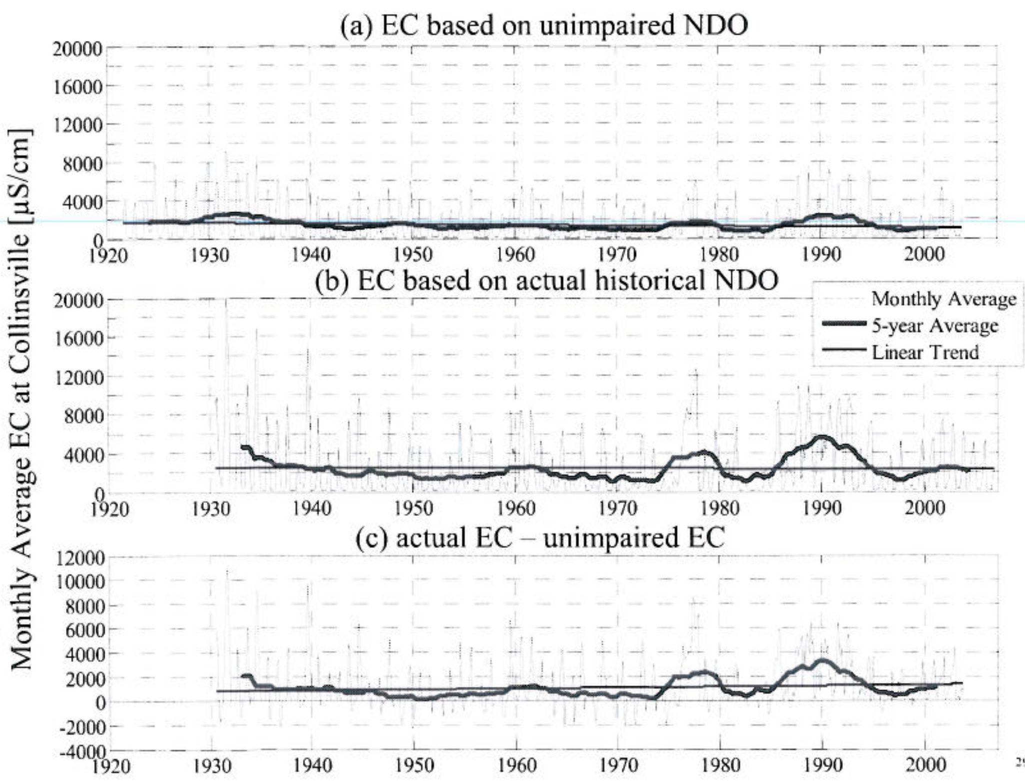



**Figure D-15 – Estimates of Collinsville salinity using the G-model for unimpaired and actual historical flow conditions**

Historical (actual) NDO during the 1930's was relatively low, sometimes averaging about -3,000 cfs for several months under actual conditions. The low values of NDO result in the high variability of estimated salinity in the 1930's under actual historical conditions.

The effects of water management on salinity at Collinsville are highlighted in Figure D-16, which shows the estimated salinity under actual historical conditions as a percent change from the unimpaired conditions. The data in Figure D-16 are the change in G-model estimates of salinity at Collinsville for the period of 1956-2003, computed as the difference between actual and unimpaired salinity as a percent change from the unimpaired salinity. Positive values indicate an increase in salinity under actual conditions and negative values indicate a decrease in salinity (freshening).

From April through August, estimated median salinity under actual historical conditions is substantially greater (more than a 100% increase) than median salinity under unimpaired conditions (Figure D-16). For the remainder of the year, there are no substantial differences between the estimates of median salinity under unimpaired and actual conditions. These distributions of estimated salinity indicate that water management practices result in significant increase in salinity throughout the year at Collinsville.

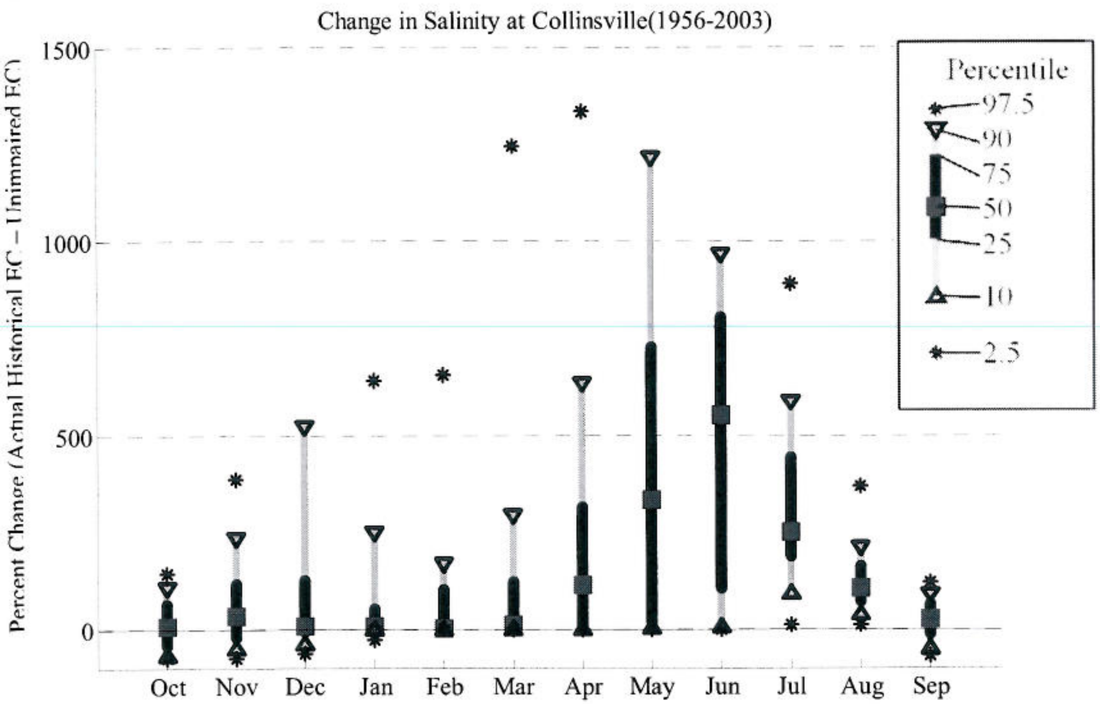



**Figure D-16 – Estimated change in salinity at Collinsville under actual historical conditions, as a percent change from unimpaired conditions, 1956-2003**

Figure D-17 shows the estimated salinities at Collinsville under actual historical and unimpaired conditions for just the more recent years (1994-2003). Positive values again indicate an increase in salinity under actual conditions and negative values indicate a decrease in salinity. The effects of water management on fall salinity are greater during this recent period 1994-2003 than during the longer period (1956-2003), but the effects during the recent period in the spring and early summer are smaller. This response reflects implementation of the X2 regulatory requirements agreed upon in the 1994 Bay-Delta Accord and regulated by the subsequent 1995 Water Quality Control Plan.

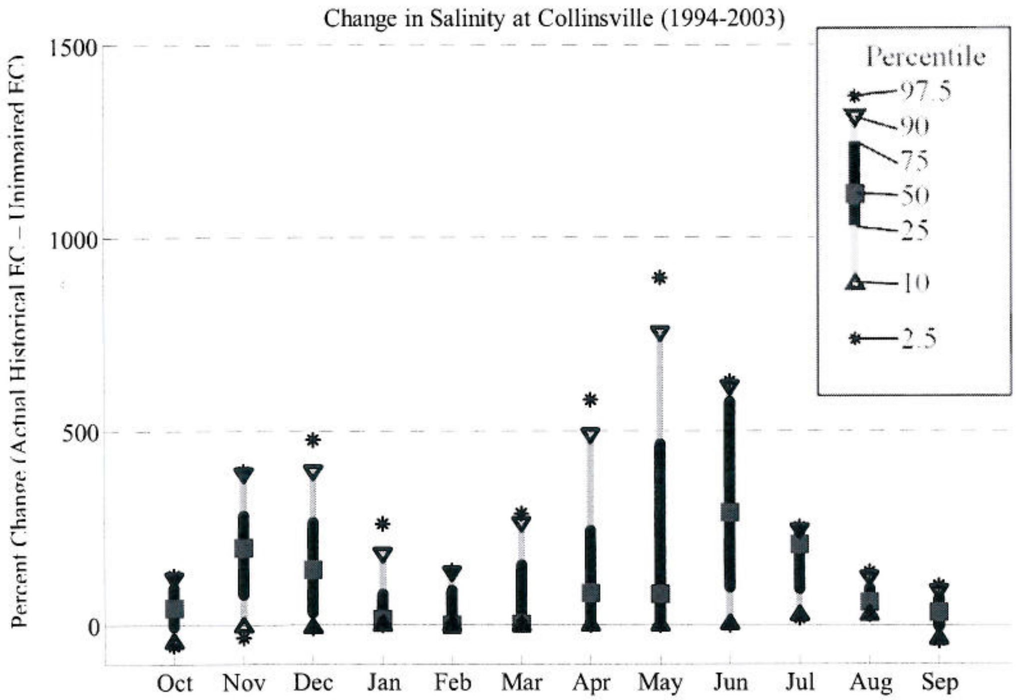



**Figure D-17 – Estimated change in salinity at Collinsville under actual historical conditions, as a percent change from unimpaired conditions, 1994-2003**

## D.3.3. Fall Salinity in the Western Delta

Figure D-18 shows the average fall salinity (October-December) at three stations in Suisun Bay and the western Delta (Chipps Island, Collinsville, and Jersey Point). The fall salinity data categorized according to the pre-Endangered Species Act (ESA) period of 1964-1992 and the post-ESA period (1993-2006)[8]. Figure D-18 illustrates that there has been a noticeable increase in fall salinity since the release of the ESA biological opinions for winter-run salmon and Delta smelt in 1993. These increases occur during normal water years, when total annual runoff ranges from 15 to 30 MAF. During very wet years, there are large Delta outflows and the ESA limits do not affect water operations. Similarly, during very dry years, the biological opinions do not have a large effect on water operations because upstream reservoir storage is low and exports from the south Delta are already small.

[8] In 1993, delta smelt and winter-run salmon were listed under the California ESA, triggering new water management regulations.

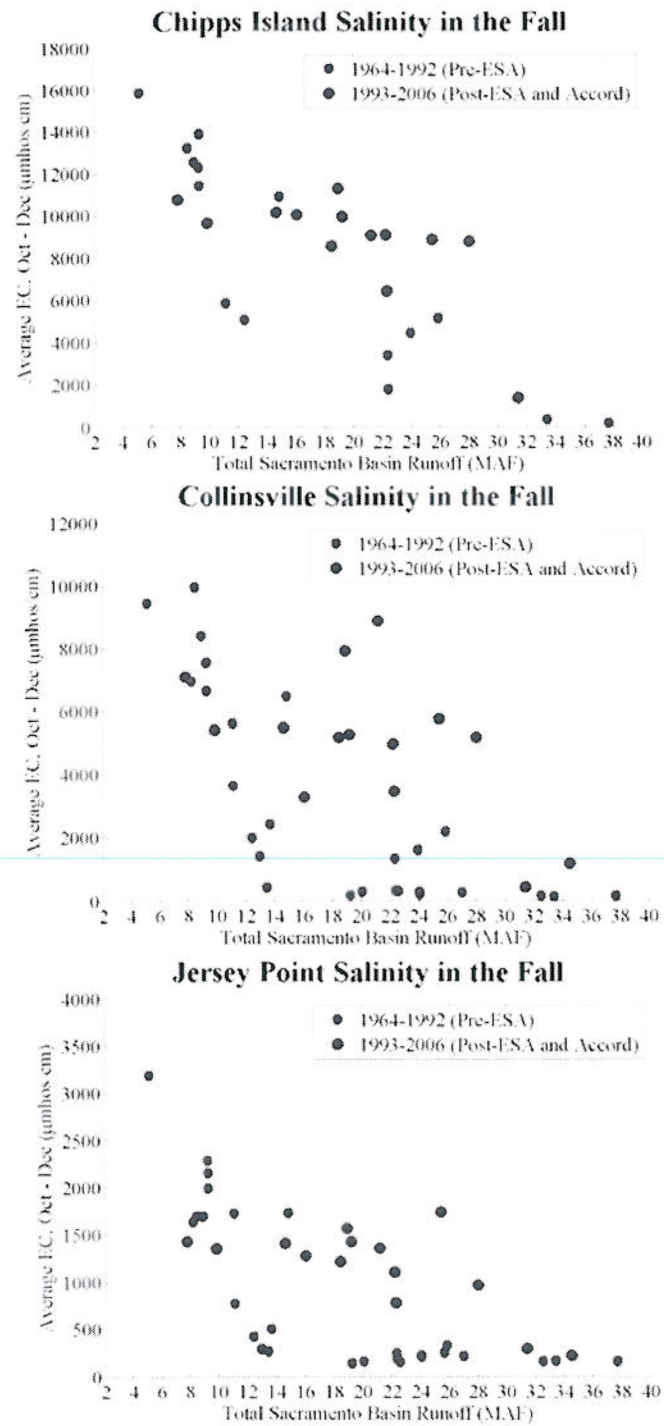



**Figure D-18 – Post-ESA salinity in the Suisun Bay and western Delta**

Figure D-19 shows the observed salinity at Chipps Island during the fall (October-December) for the period of 1976-1992 (pre-ESA) and 1993-2005 (post-ESA). Fall salinity at Chipps

Island during normal years is now comparable to fall salinity during dry and critical years prior to 1994.

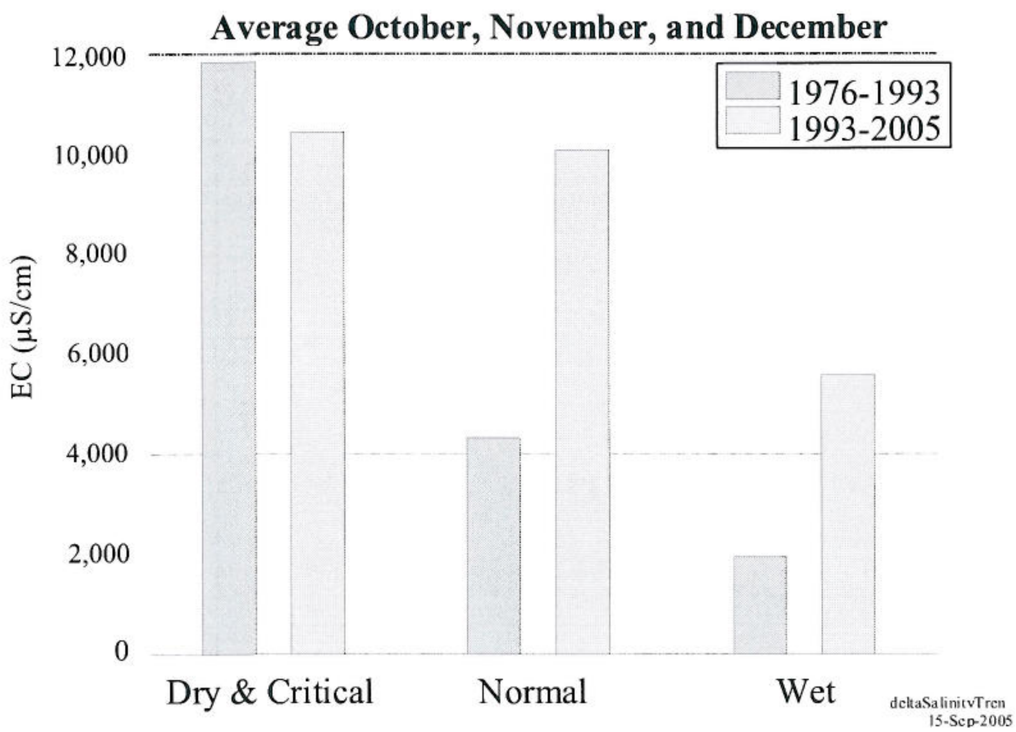



**Figure D-19 – Increase in Fall Salinity at Chipps Island**

## D.4. General conceptual overview of salinity changes

### Observed changes in seasonal salinity with time

The salinity regime in the western Delta has changed as the level of development has increased and water project operations have changed due to regulatory requirements. The comparison of three decades with similar hydrology in Figure D-20 presents a conceptual illustration of the changing salinity regime in Suisun Bay and the western Delta.

Monthly-averaged salinity in the spring and summer was substantially greater from 1966 through 1975 than during the early 1900's. However, fall and early winter salinity was lower than the early 1900's. This reduction in salinity in the fall and early winter was likely due in part to CVP and SWP reservoir releases for flood control purposes in the fall, which freshened the Delta. Flood control releases during this period were large because CVP and SWP diversions and exports were not fully developed and upstream reservoirs were often above flood control maximum storage levels in the fall, entering the wet season.

Salinity during 1995 through 2004, however, exceeded the salinities in the early 1900's during all months, for years with similar hydrologic conditions. The dramatic increase in fall salinity relative to observed levels from 1966 to 1975 is accompanied by a slight decrease in spring and summer salinity. This is likely due to minimum flow and X2 requirements imposed by the State Water Resources Board in 1995. However, spring and summer salinities remain much greater relative to salinity in the early 1900's.

The range of seasonal variability during 1966-1975 was greatly reduced because the Delta did not get as fresh as it did in the early 1900's. During the last decade, seasonal variability has increased such that the range of salinity observed in the Delta over the course of a year is similar to that in the early 1900's. However, salinity intrusion has moved inland relative to the early 1900's, resulting in saltier conditions in the Suisun Bay and western Delta and a reduction in the period when fresher water is available.

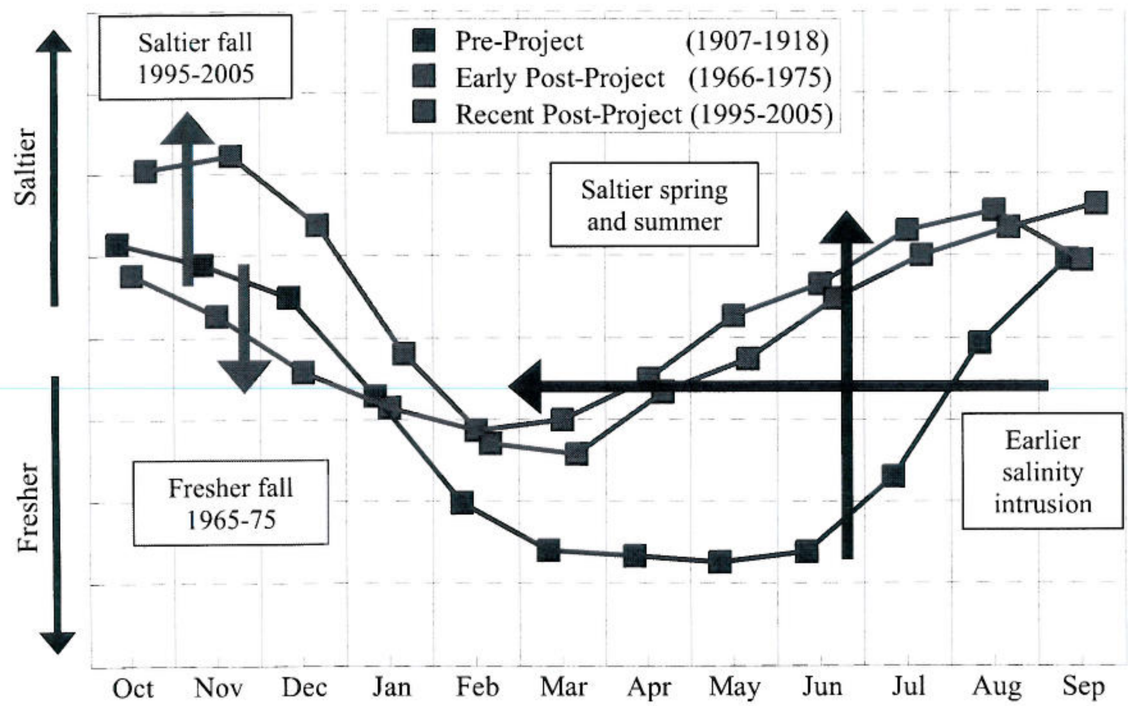



**Figure D-20 – Conceptual plot of seasonal variability of salinity in Suisun Bay and the western Delta during different water management eras**

## The effect of water management for wet and dry years

Water management has the largest effect during dry years when the Delta stays relatively salty throughout the year with limited seasonal variability compared to unimpaired conditions. As shown conceptually in Figure D-21, during wet years the Delta freshens as much as it would under unimpaired conditions, but the Delta does not stay fresh for as long.

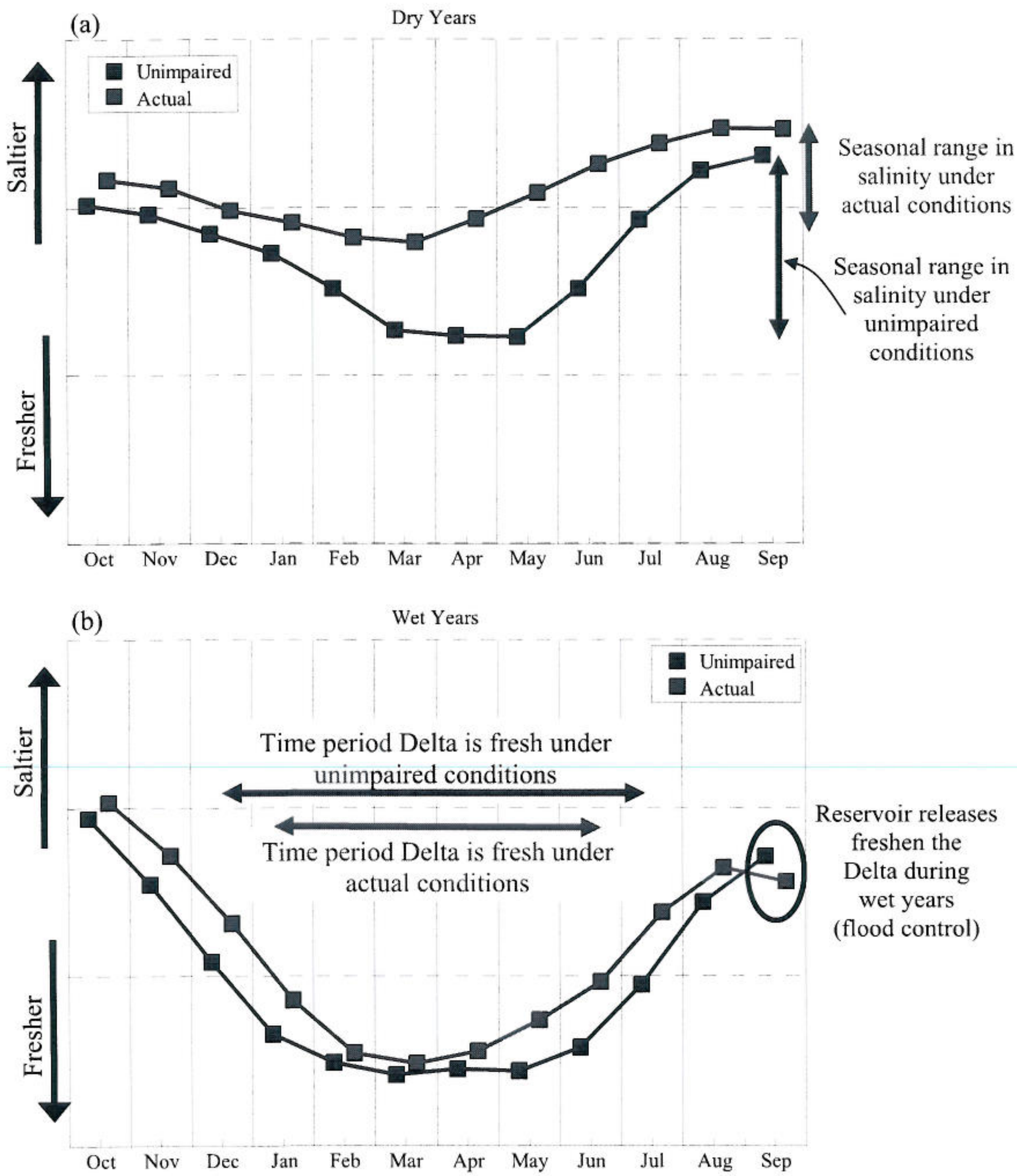



**Figure D-21 – Conceptual plot of seasonal salinity variations in the Delta under actual historical conditions compared to unimpaired conditions in (a) dry years and (b) wet years**

# Appendix E. Qualitative Salinity Observations

The earliest written accounts of explorers were often concerned with adequate drinking water, and salinity was generally described in qualitative terms, such as "brackish," "fresh," or "sweet." For the purposes of comparing the present-day water quality with the historical conditions, these qualitative observations need to be quantified.

Testimony from Antioch Case (Town of Antioch v. Williams Irrigation District, 188 Cal. 451) indicated early settlers required water with less than 100 mg/L of chloride (approximately 525 μS/cm EC) for municipal use.[9] Similarly, DPW (1931) indicated that a "noticeable" level of salinity was 100 mg/L chloride. The current secondary water quality standard for municipal and industrial use is 250 mg/L chloride (1,000 μS/cm EC) (SWRCB 2006; US EPA 2003). This report assumes a value of 250 mg/L chloride (equivalent to 1000 μS/cm EC) to be the demarcation between "fresh" (or "sweet") water and "brackish" water.

## E.1. Observations from Early Explorers

Table E-1 summarizes some reported observations of water quality made by early explorers and settlers. These observations were qualitative and were most likely only a glimpse of the ambient conditions and may not completely represent true historical water quality conditions. Moreover, these observations were from a time period when anthropogenic effects on this region were minimal and this region was close to natural conditions.

Table E-1 also lists the reconstructed Sacramento River annual flow (MAF) from Meko *et al.* (2001b) for the year of observation and for the previous year. For reference, the average Sacramento River flow from Meko *et al.* (2001b) for the period 1860-1977 is 18 MAF/yr.

**Table E-1 – Qualitative salinity observations from early explorers**

| Date | Location | Description | Year / Reconstructed Flow [MAF] | Observer | Reference |
|---|---|---|---|---|---|
| 1775 August | near the Sacramento-San Joaquin confluence | sweet, the same as in a lake | 1774 / 25<br>1775 / 19 | Canizares | Britton, 1987 in Fox, 1987b |
| 1776 April | near Antioch (San Joaquin River) | very clear, fresh, sweet, and good | 1775 / 19<br>1776 / 9 | Font | Britton, 1987 in Fox, 1987b |
| 1776 September | near the Sacramento-San Joaquin confluence | sweet | 1775 / 19<br>1776 / 9 | Canizares | Britton, 1987 in Fox, 1987b |

9 Supplement to Respondent's Answering Brief, p. 10.

| Date | Location | Description | Year / Reconstructed Flow [MAF] | Observer | Reference |
|---|---|---|---|---|---|
| 1796 | unknown | salinity "far upstream" at high tide | 1795 / 6<br>1796 / 10 | Hermengildo Sal | Cook, 1960 in TBI, 1998 |
| 1811 October | near the Sacramento-San Joaquin confluence | sweet | 1810 / 19<br>1811 / 23 | Abella | Britton, 1987 in Fox, 1987b |
| 1841 August | Three Mile Slough north of Emmaton | brackish (undrinkable) | 1840 / 16<br>1841 / 6 | Wilkes | Britton, 1987 in Fox 1987b |

### E.1.1. Fresh Conditions

Table E-1 indicates that some early explorers observed "sweet" water near the confluence of the Sacramento and San Joaquin Rivers both in relatively wet years (August of 1775 and October of 1811, reconstructed runoff about 19 MAF/yr) and in relatively dry years (September of 1776, reconstructed runoff about 9 MAF/yr). Except as noted, it is unknown whether these observations were made at high tide or low tide.

In order to provide a context for these anecdotal observations, present-day observed monthly salinity (EC) conditions at Collinsville (located near the confluence of Sacramento and San Joaquin Rivers) are plotted against unimpaired annual Sacramento River flow in Figure E-1. The observed data are monthly-averaged salinity (μS/cm) during August-October for the period 1965-2005. The data for the post-ESA years (1994-2005) are shown as shaded circles. Note that the anecdotal observations in Table E-1 are likely "one-time" observations, while those shown in Figure E-1 are average monthly values.

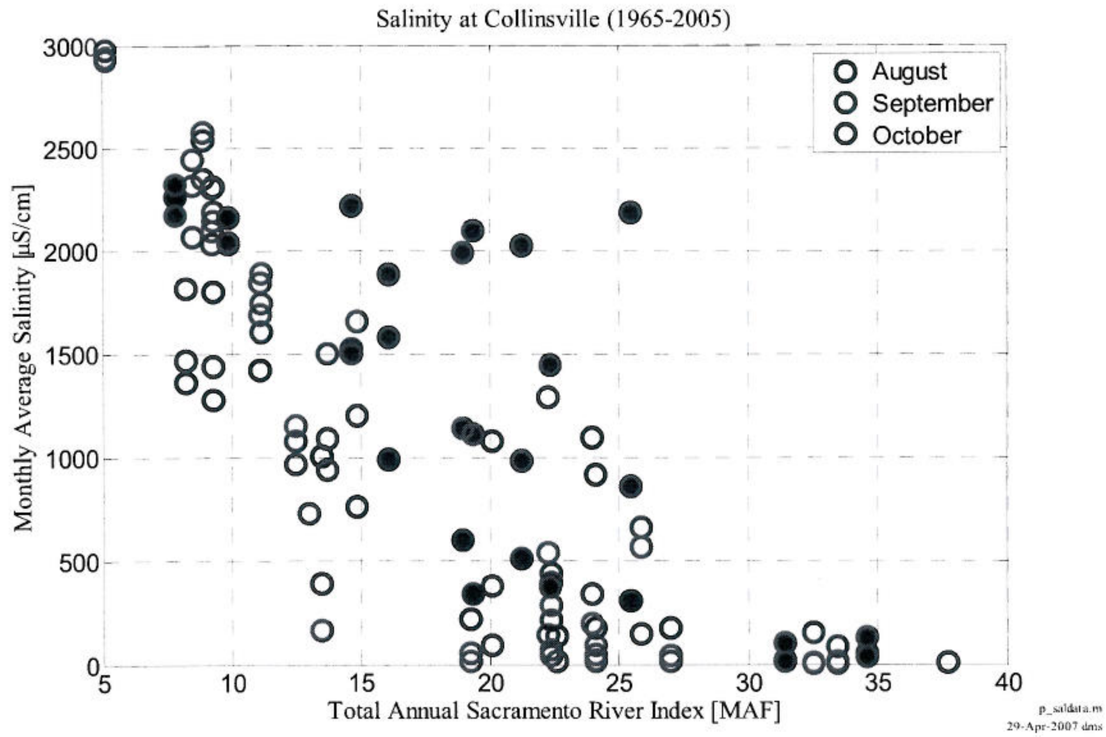



**Figure E-1 – Observed salinity at Collinsville, 1965-2005**

Under current management conditions, the monthly average salinity at Collinsville from August through October is only less than 1,000 µS/cm EC (the interpretation of the "sweet" threshold for drinking water) when the unimpaired runoff is greater than about 20 to 25 MAF/yr (Figure E-1). This suggests either the "sweet" threshold used in this report is too small, or salinity at Collinsville is higher today than it was in the late 18th and early 19th centuries.

If the definition of the "sweet" threshold is changed to 1,300 µS/cm EC and the post-ESA years (1994-2005) are excluded, then the monthly-averaged salinity at Collinsville during August-October is "fresh" (less than 1,300 µS/cm EC) when runoff is greater than 16 MAF/yr. This corresponds better to the anecdotal observations, discussed above, but suggests a recent increase in salinity at Collinsville during moderately wet years (with runoff between 14 and 26 MAF/yr). In 5 of the 12 post-ESA years (1997, 1999, 2000, 2003 and 2004), the water at Collinsville in October would not be considered "sweet" even under the relaxed criterion of 1,300 µS/cm EC, suggesting that October salinity under present conditions could be greater than it was in 1811.

## E.1.2. Brackish Conditions

The qualitative observations of high salinity intrusion in Table E-1 are less specific about location. However, some of these observations have been interpreted by others (Cook, 1960, in TBI, 1998; Fox, 1987b) to indicate intrusion as far upstream as Rio Vista. The drought periods of 1976-1977 and 1987-1992 are similar to these periods when these qualitative observations were made. During 1976-1977, daily average salinity at Rio Vista exceeded 1,000 μS/cm for approximately six months of the year. During 1987-1992, salinity at Rio Vista at high tide often exceeded 2,000 μS/cm, particularly during the fall. This is consistent with the anecdotal observations made in 1796 and 1841, which report salt water extending into the western Delta.

**Summary**: Interpretation of the above observations in the context of the reconstructed Sacramento River flows shows that the Delta is generally saltier than the historical levels for equivalent runoff conditions and does not support the hypothesis that the present-day Delta is managed as a freshwater system in comparison with its historical salinity regime. Moreover, this analysis indicates that salinity in the western Delta has increased during September and October in the recent years (post-1994 period).

## *E.2. Observations from early settlers in the Western Delta*

Observations from early settlers in the western Delta provide a more complete description of salinity in the late 1800's and early 1900's than the observations from early explorers discussed earlier. Assuming the early settlers inhabited a particular region for longer time periods than the early explorers, observations from the early settlers capture the temporal variability better than those from the early explorers.

### E.2.1. Town of Antioch Injunction on Upstream Diverters

In 1920, the Town of Antioch filed a lawsuit against upstream irrigation districts alleging that the upstream diversions were causing increased salinity intrusion at Antioch. The court decision, legal briefings, and petitions provide salinity observations from a variety of witnesses. Although anecdotal testimony summarized in these legal briefs is far from scientific evidence, it provides a perspective of the salinity conditions prevailing in the early 1900's. Because the proceedings were adversarial in nature, this report focuses on the testimony of the upstream interests, who were trying to demonstrate that salinity intrusion was common near Antioch prior to their diverting water (prior to 1920). Consequently, the testimony may be biased in support of this "more saline" argument. Nonetheless, these anecdotal testimonies indicate that the western Delta was less salty in the past than it is today. Analyses of some of the testimonies are presented below.

**Case History**

On July 2, 1920, the Town of Antioch filed suit in the Superior Court of the State of California (hereinafter referred to as the "Antioch Case") against upstream diverters on the Sacramento River and Yuba River. A hearing for a temporary injunction began on July 26, 1920, and lasted approximately three months. On January 7, 1921, Judge A. F. St. Sure granted a temporary injunction, restraining the defendants "from diverting so much water from the said Sacramento River and its tributaries, to non-riparian lands, that the amount of water flowing past the City of Sacramento, in the County of Sacramento, State of California, shall be less than 3500 cubic feet per second" (Town of Antioch v. Williams Irrigation District, Supplement to Appellants' Opening Brief, p. 13).

The defendants appealed to the Supreme Court of the State of California, which issued its opinion on March 23, 1922. The Supreme Court reversed the lower court and withdrew the injunction, declaring "[i]t is evident from all these considerations that to allow an appropriator of fresh water near the outlet of these two rivers to stop diversions above so as to maintain sufficient volume in the stream to hold the tide water below his place of diversion and secure him fresh water from the stream at that point, under the circumstances existing in this state, would be extremely unreasonable and unjust to the inhabitants of the valleys above and highly detrimental to the public interests besides."

The Supreme Court did not make any comment whatsoever on the evidence of salinity intrusion prior to the upstream diversions in question. The Court indicated that their decision was based on a "policy of our law, which undoubtedly favors in every possible manner the use of the waters of the streams for the purpose of irrigating the lands of the state to render them fertile and productive, and discourages and forbids every kind of unnecessary waste thereof." (Town of Antioch v. Williams Irrigation District (1922) 188 Cal. 451). The Court concluded that allowing 3,500 cubic feet per second (cfs) to "waste" into the Bay to provide less than 1 cfs of adequate quality water for the Town of Antioch would constitute unreasonable use of California's limited supply of water.

The court did not base their decision on historical salinity observations at Antioch, which indicate that Antioch was able to divert freshwater at low tide at all times from 1866 to 1918, except possibly for some fall months during some dry years (Section 3.1).

### E.2.2. Salinity at Antioch – then and now

In the present day, the City of Antioch maintains a municipal water intake on the San Joaquin River at Antioch. As a general operating rule, the City of Antioch pumps water from the river when salinity at the intake is less than 1,000 μS/cm EC. Salinity varies substantially with the tide; generally the greatest salinity is observed near high tide and the lowest salinity is observed at low tide. Figure E-2 shows that salinity in the San Joaquin River at Antioch is highly variable and is dependent on tidal conditions and season. Figure E-2 indicates that for water year 2000 (an above-normal water year) the City of Antioch could pump water all day for about four and half months (early February through mid-June) and could pump for a portion of the day at low tide for another three and half months (mid-June through September). For the remaining four months (October-January), water at Antioch's intakes exceeded 1,000 μS/cm EC for the entire day, regardless of tidal phase.

Testimony from multiple witnesses in the Antioch Case indicates that fresh water was always available in the San Joaquin River at Antioch at low tide until just prior to 1920. Antioch's legal position was that fresh water was always available before upstream development. In cross-examination of Antioch's witnesses, the upstream irrigators demonstrated that brackish conditions did occasionally exist at high tide.

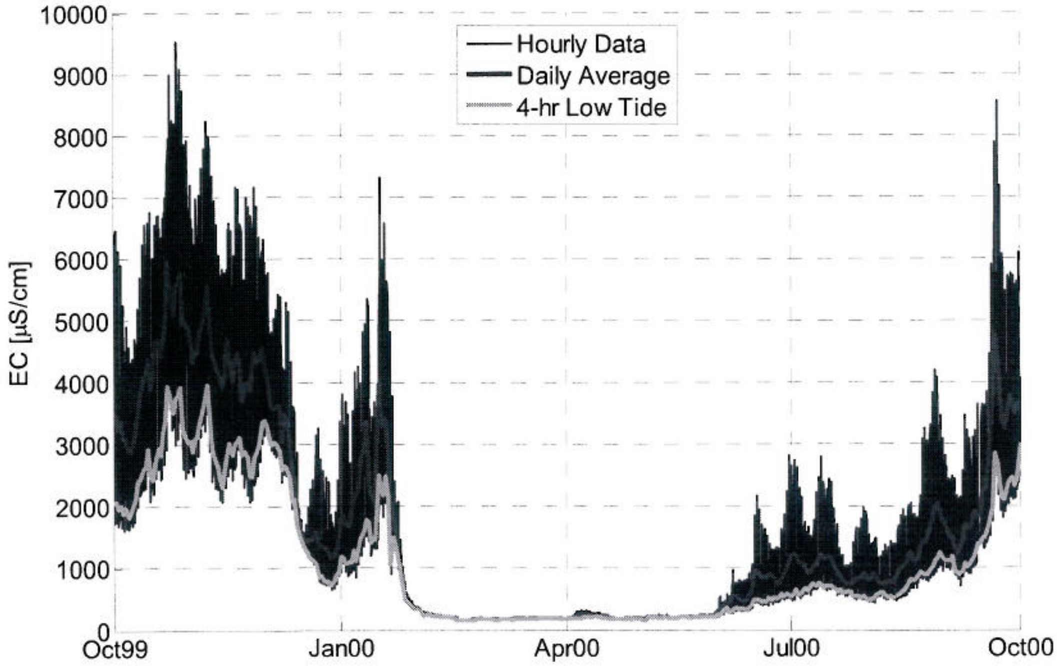



**Figure E-2 – Salinity variations in the San Joaquin River at Antioch, water year 2000**

Figure E-3 shows the distribution of low tide salinity (salinity during the freshest 4 hours of each day) for the period of May 1, 1983 through September 30, 2002.[10] These data indicate that, on average (in 50% of the water years), low tide salinity exceeds 1,000 µS/cm EC from late-August through December. The data in Figure E-3 provide context for the qualitative observations from the Antioch Case. During the driest 25% of the years (5 out of 20 years), low tide salinity exceeds 1,000 µS/cm EC from June through January, leaving the Antioch intake with no fresh water for eight months of the year.

Under average conditions corresponding to the period 1983-2002, Antioch would have to stop pumping from late August to late December in 10 of the 20 years; i.e., they would have an average of eight months of low-tide pumping per year, compared to the pre-1915 average of twelve months per year (based on the anecdotal information filed by the Appellants (upstream diverters) in the Antioch Case).

[10] Data Source: Interagency Ecological Program, HEC-DSS Time-Series Databases. Station RSAN007. Agency: DWR-ESO-D1485C. Measurement: 1-hour EC. Time Range: May 1, 1983 through September 30, 2002

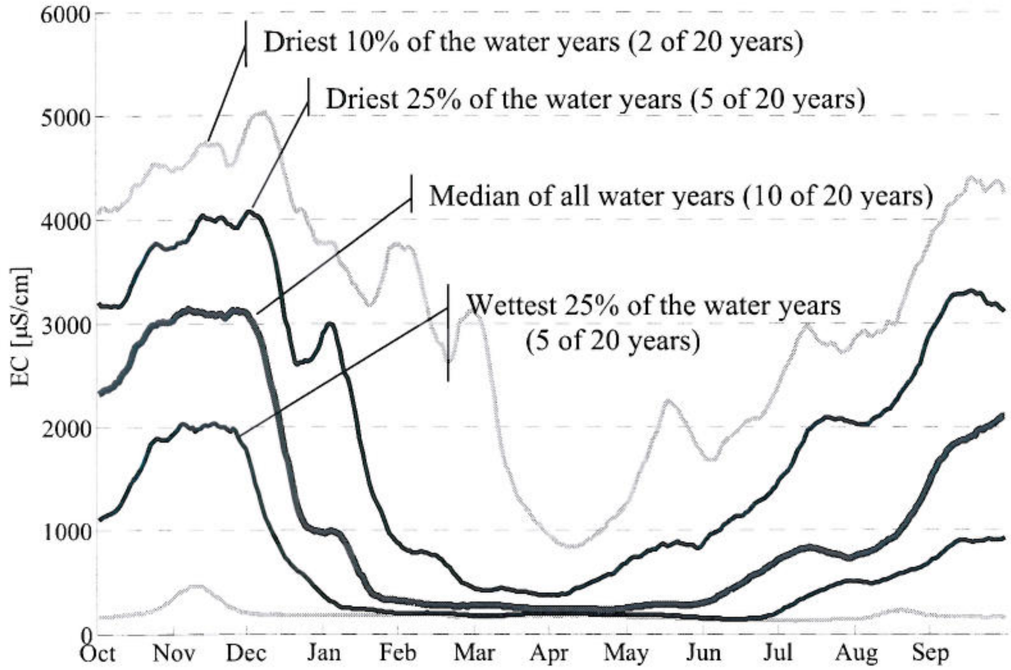



**Figure E-3 – Seasonal Distribution of low-tide salinity at Antioch, 1983-2002**

## *Conclusions*

- The window, when Antioch is able to pump water with salinity less than 1,000 µS/cm EC, has substantially narrowed in the last 125 years.
- Antioch was apparently able to pump fresh water at low tide year-round in the late 1800's, with the possible exception of the fall season during one or two dry years.
- During 10 of the 20 years between 1983 and 2002, salinity was less than 1,000 µS/cm EC at low tide for only about eight months of the year.
- During the driest 5 years between 1983 and 2002, salinity was less than 1,000 µS/cm for only about four months per year; i.e., no fresh water was available at any time of the day for about eight months of the year.

### E.2.3. Salinity at Kentucky Point on Twitchell Island – then and now

The appellants in the Antioch Case, representing the upstream diverters, identified one resident of Twitchell Island who reported the water at Kentucky Landing was brackish on "one or two occasions" between 1870 and 1875 during August and September. During this time, he had to travel up the San Joaquin River to Seven Mile Slough (the eastern boundary of Twitchell Island) and sailed as far as the mouth of the Mokelumne River (approximately 2 miles further up the San Joaquin River than the Seven Mile Slough junction) to obtain fresh drinking water.

For comparison, we look at salinity monitoring data in that region for 1981 and 2002 to see the location of potable water.[11] The source document (Town of Antioch v. Williams Irrigation District, 188 Cal. 451) for the 1870's drought uses up to 100 mg/L chloride concentration as the threshold for a potable water supply. Monitoring data from 1981 shows similar salinity intrusion as described by the Twitchell Island resident; salinity along the San Joaquin River at Bradford Island (about 1.5 miles upstream of Three Mile Slough) exceeded 1,000 µS/cm EC (about 250 mg/L Cl) during August and September. During the same time period, salinity was around 400 µS/cm EC (about 64 mg/L Cl) approximately 5 miles upstream on the San Joaquin River between Seven Mile Slough and the Mokelumne River. This comparison indicates that the extent of salinity intrusion in 1981 is similar to that which occurred in 1870 and 1871.

Similarly, in September 2002, the salinity in the San Joaquin River at San Andreas landing (less than 2 miles downstream of the Mokelumne River mouth) peaked at 977 µS/cm EC, which corresponds to approximately 225 mg/L chloride concentration. Therefore, if the observer was to travel upriver for potable water in 2002, they would have likely traveled up to the mouth of the Mokelumne River as they did in 1870. Salinity intrusion in critically dry years is even farther into the Delta than was found in 2002.

In conclusion, salinity intrusion up the San Joaquin River during the dry years of 1870 and 1871 as described by a Twitchell Island resident is consistent with salinity intrusion in 1981 and 2002 under similar hydrological conditions. There is no evidence that salinity intrusion during the drought of 1870-71 was more extensive than salinity intrusion during similar water years in the current salinity regime.

[11] 1981 and 2002 were both dry water years in the Sacramento River basin as defined in D-1641 with similar annual unimpaired Sacramento River flow to the years 1870 and 1871. Annual unimpaired Sacramento River flow in 1870, 1871, 1981, and 2002 was 11 MAF, 10 MAF, 11 MAF, and 14 MAF, respectively.